The development of hermetic TPC for the DARWIN experiment

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Nagoya Workshop on Technology and Instrumentation in Future Liquid Noble Gas Detectors
2024.02.14-16

NAGOYA UNIVERSITY

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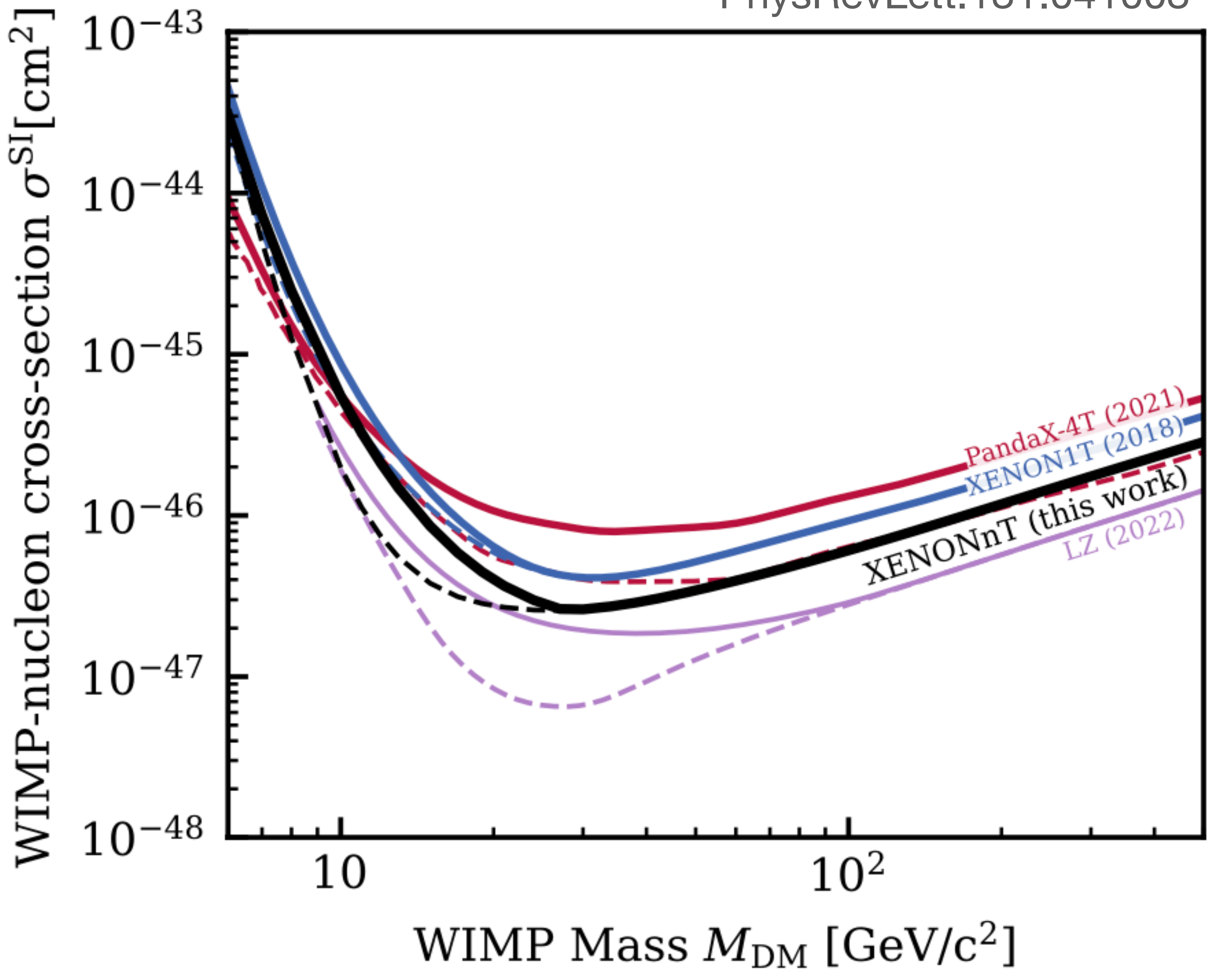
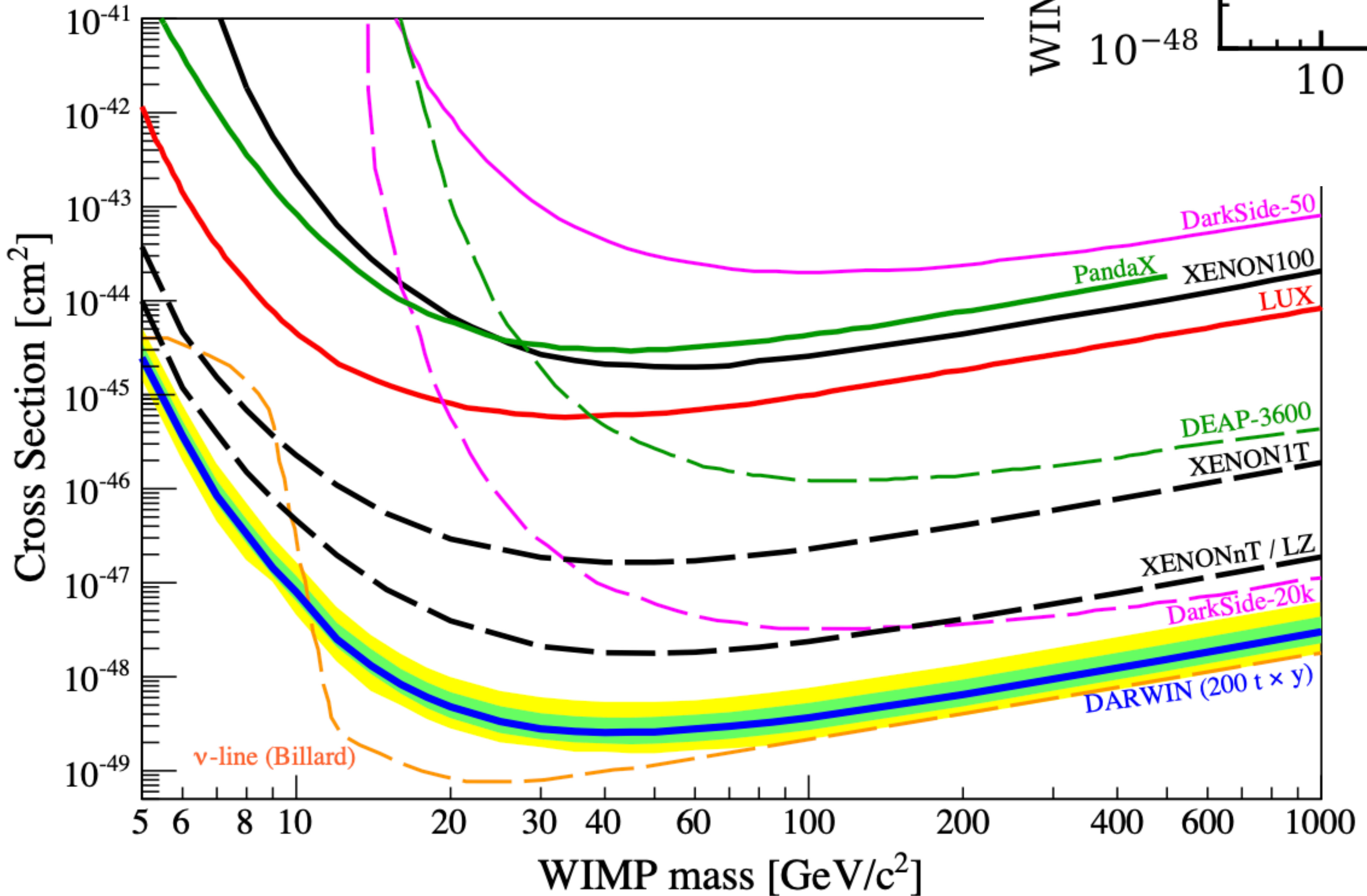
Introduction: future DM direct detection with LXe

- Current world limit for dark matter search, especially heavy WIMPs, are achieved by liquid xenon detectors.
    - O(10^{-46} - 10^{-47})cm^2 achieved in G2 detectors
- For future DM search: **DARWIN/XLZD** is planned with ~50 t or more of LXe.
    - Target: ~10^{-49} cm^2, aiming to reach the limitation by solar and atmospheric neutrino background (neutrino fog)

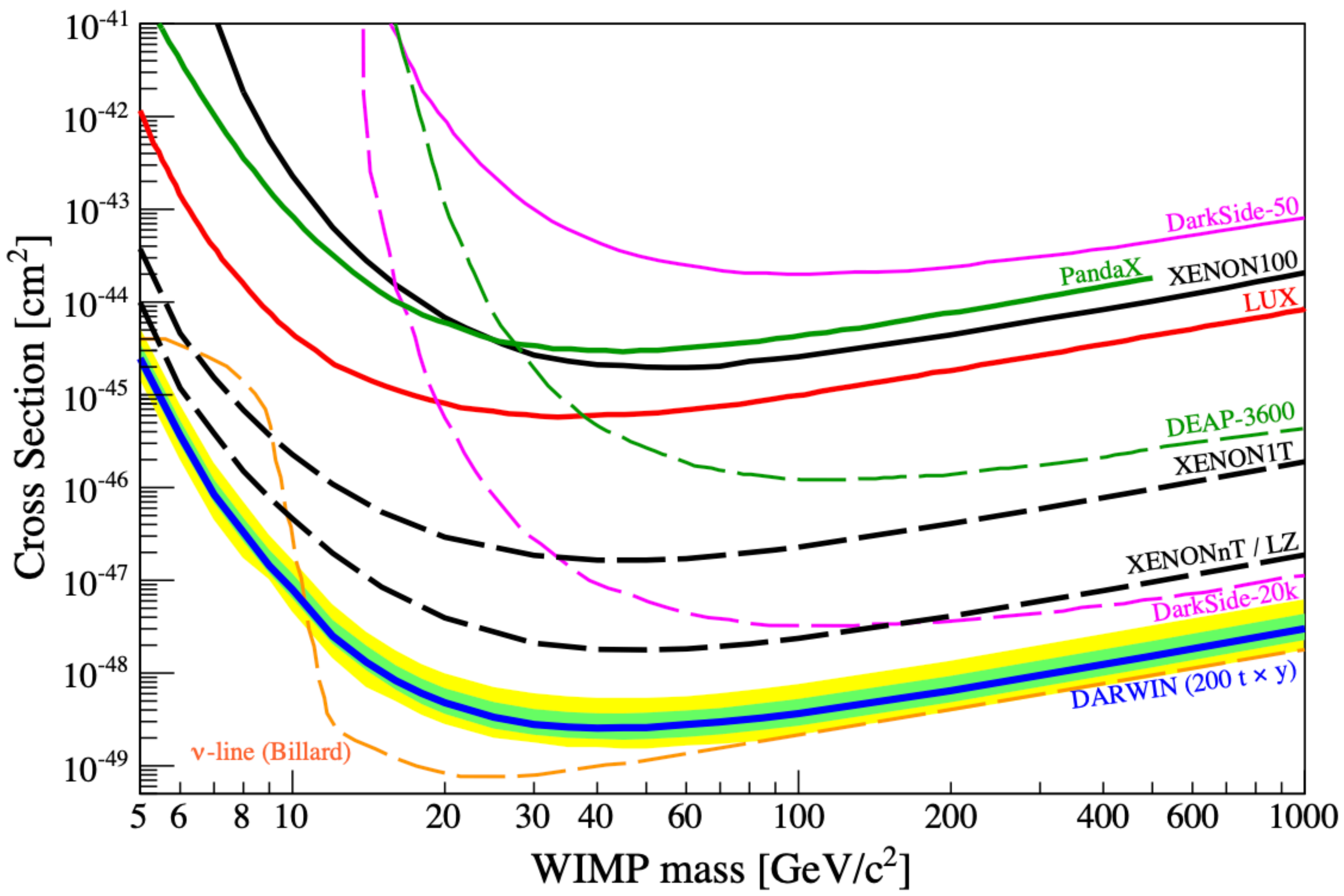
PhysRevLett.131.041003

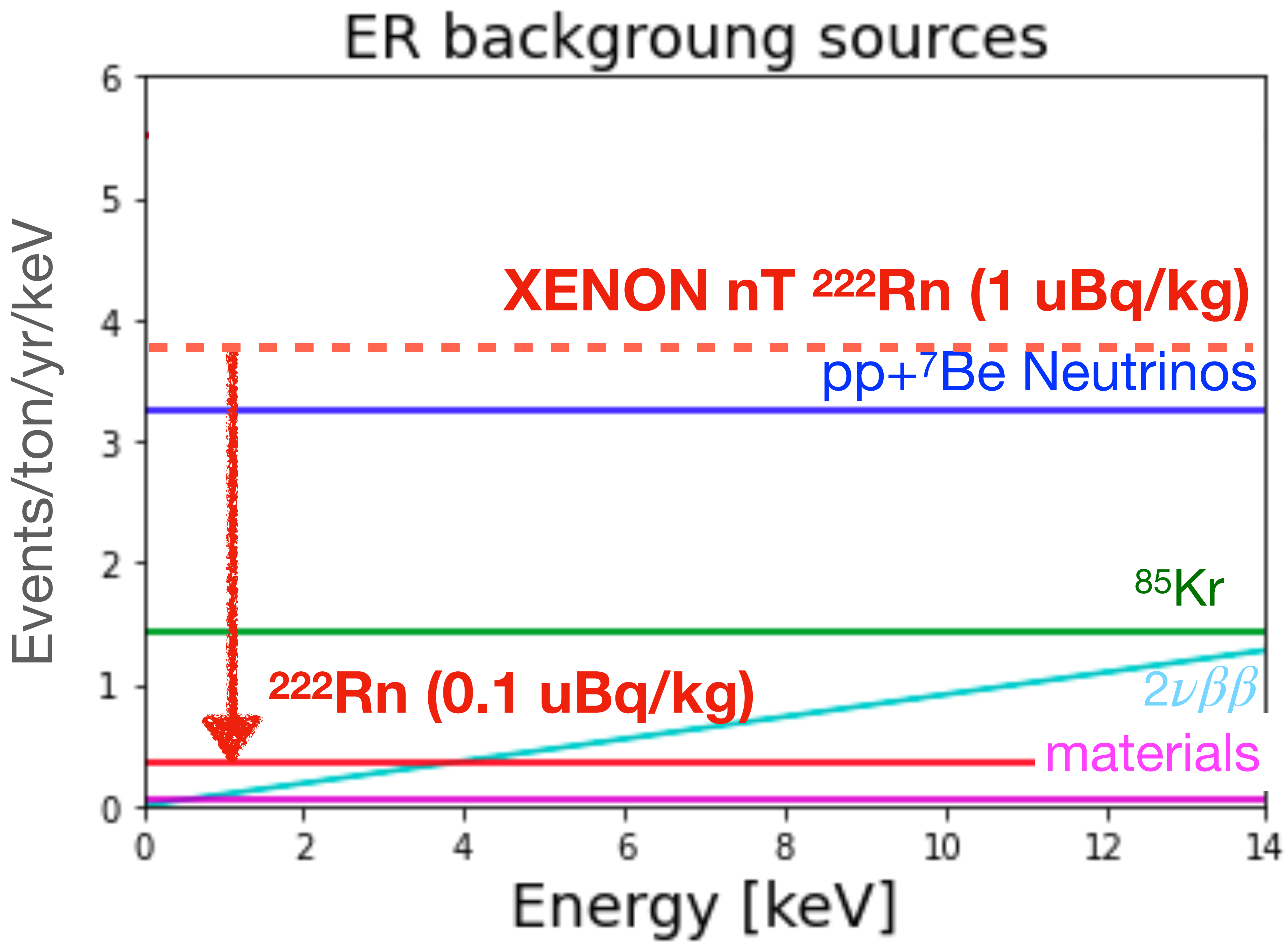


JCAP 1611 (2016) no.11, 017



Rn BG target for future detector

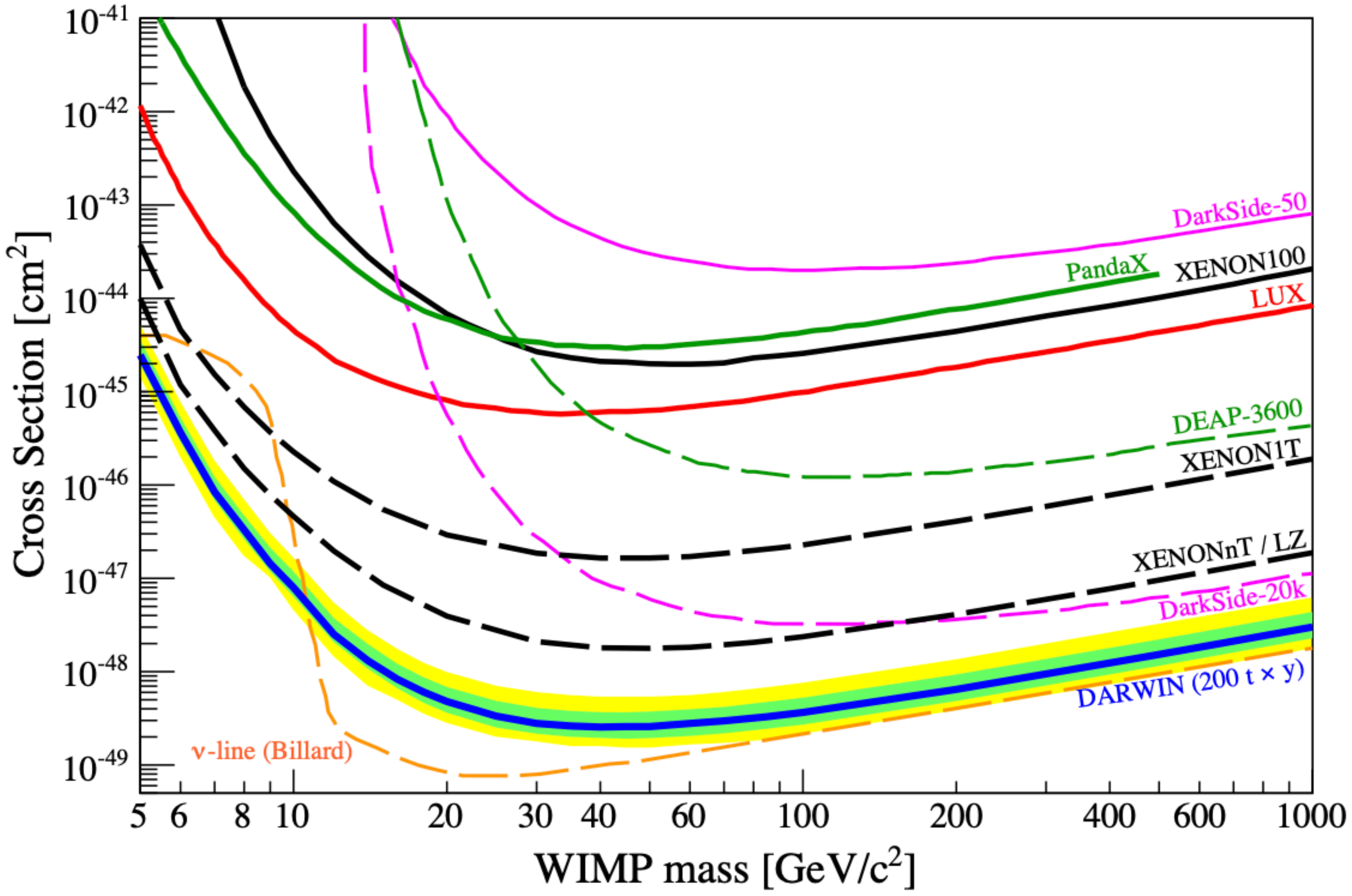




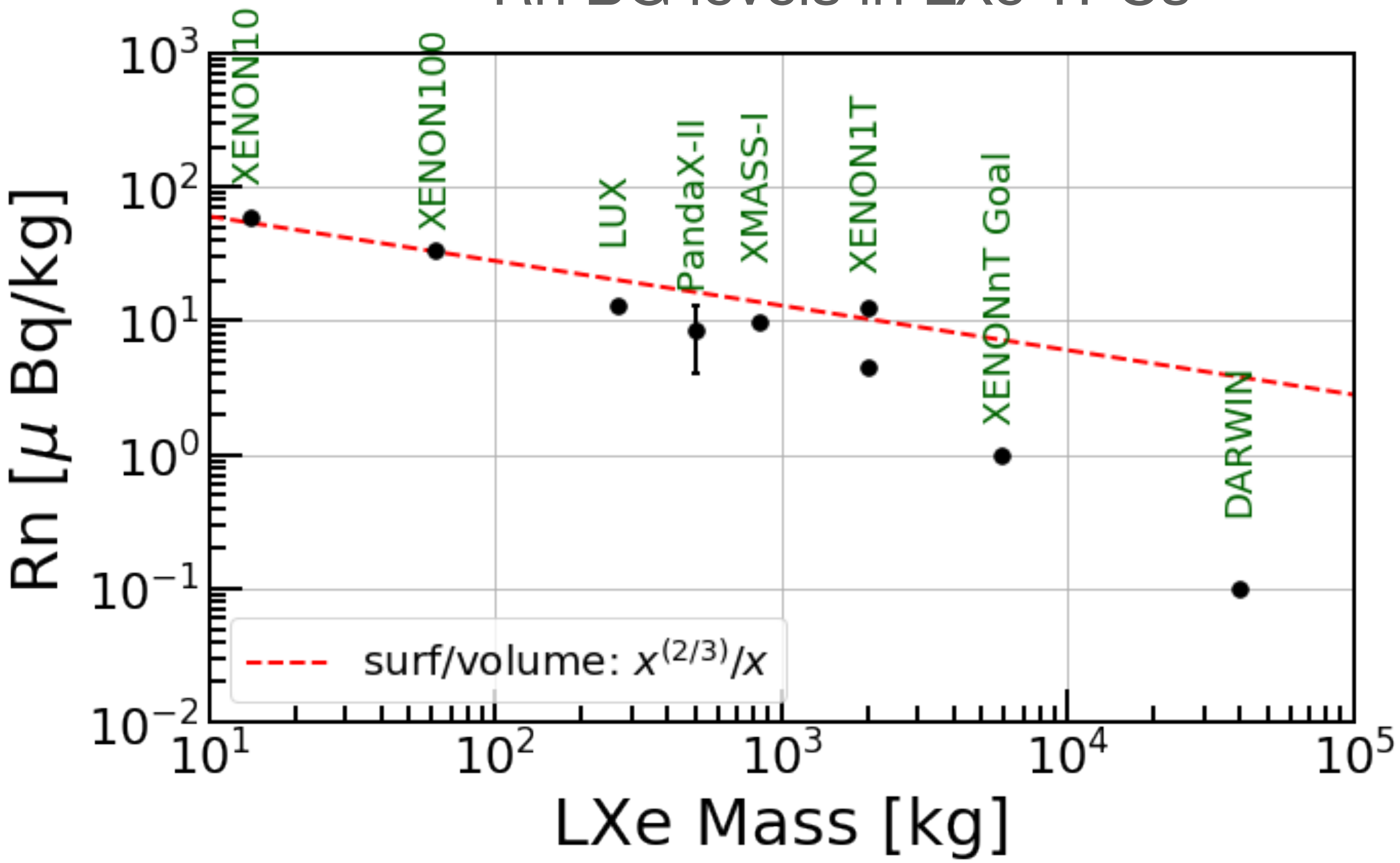
- To achieve the sensitivity ~10^{-49} cm^2, ^{222}Rn is the most serious background source

- We need **~1/10** of XENONnT target level -> How to achieve?

Rn BG target for future detector



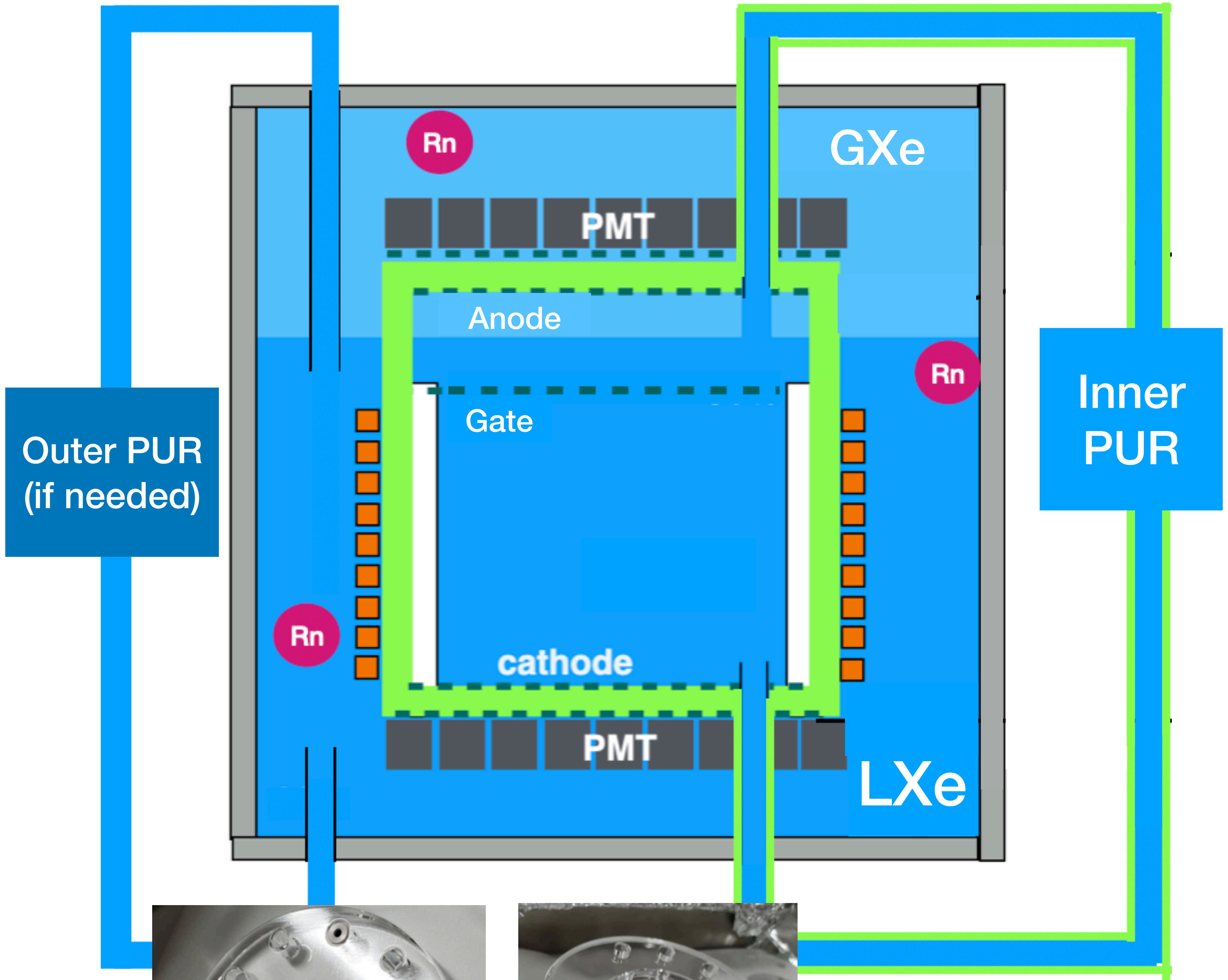
Rn BG levels in LXe TPCs

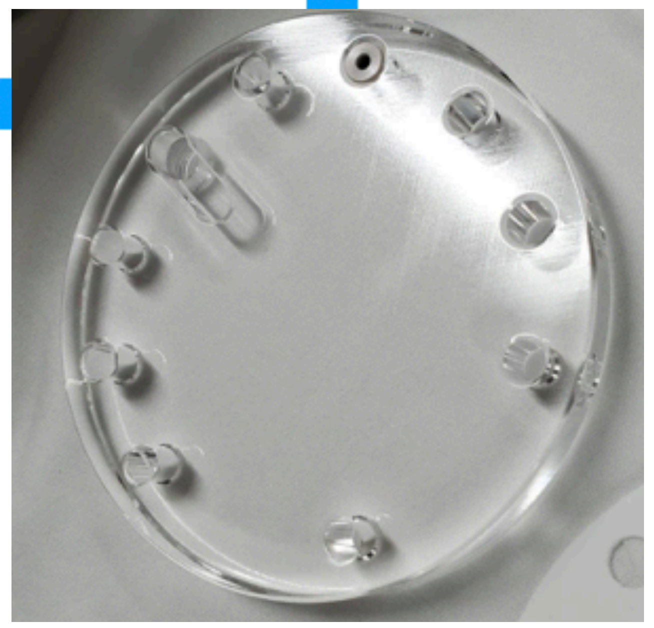


Yamashita,Dark Matter searches in the 2020s at the crossroads of the WIMP

- Improvement by surface-volume ratio is not enough:
  - Additional Rn reduction is required !

Hermetic Quartz TPC: Concepts





- To solve this issue, we are studying about **Hermetic TPC**.
  - Fully Isolating the TPC volume using Quartz/PTFE
  - VUV transparent quartz with low radio-activity
- Non-hermetic quartz TPC has been tested: PTEP, 2020, 113H02
  - Detector components are stacked without tightened
  - No significant impact in operation (ex. charge up) has been observed
- Next step: fully hermetic TPC

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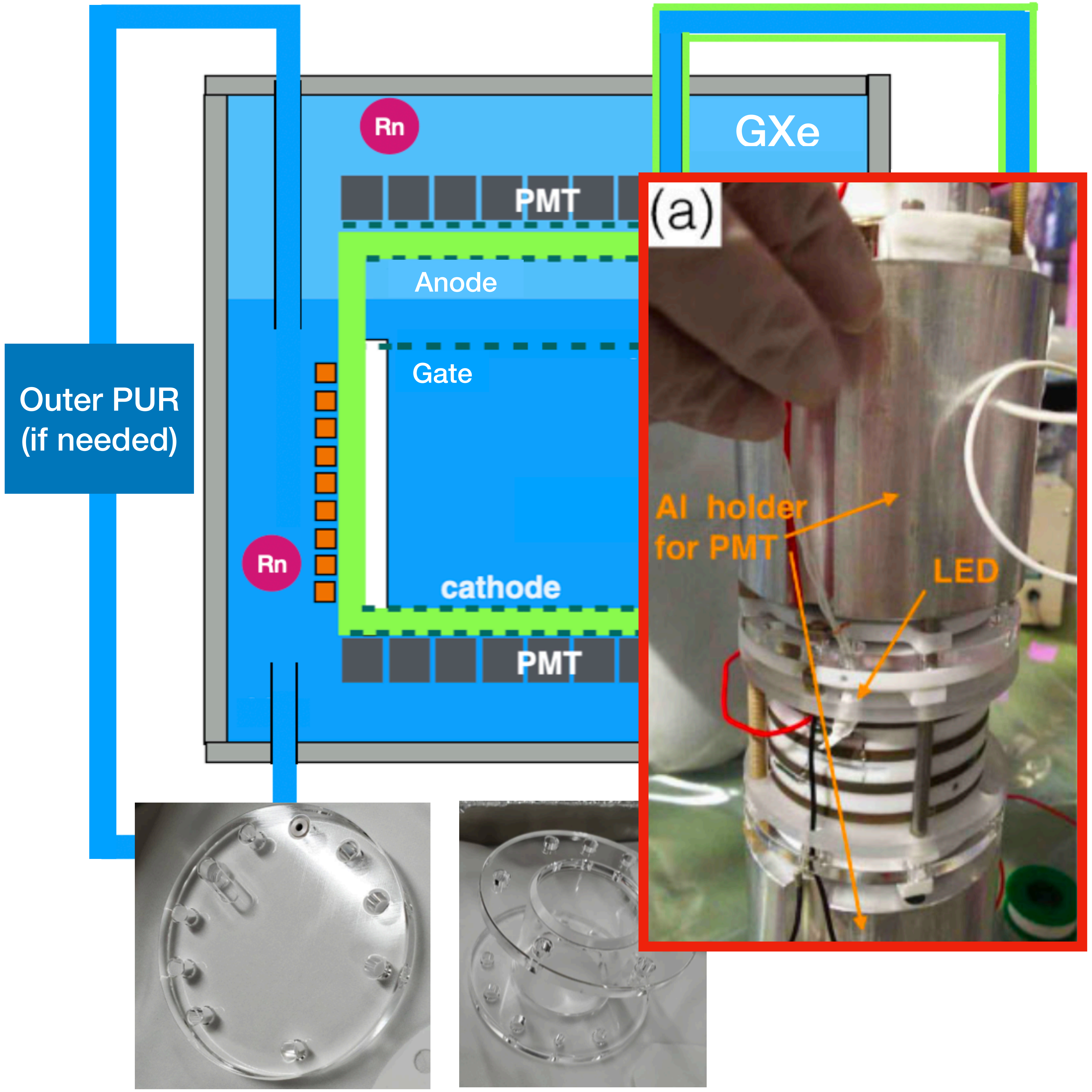

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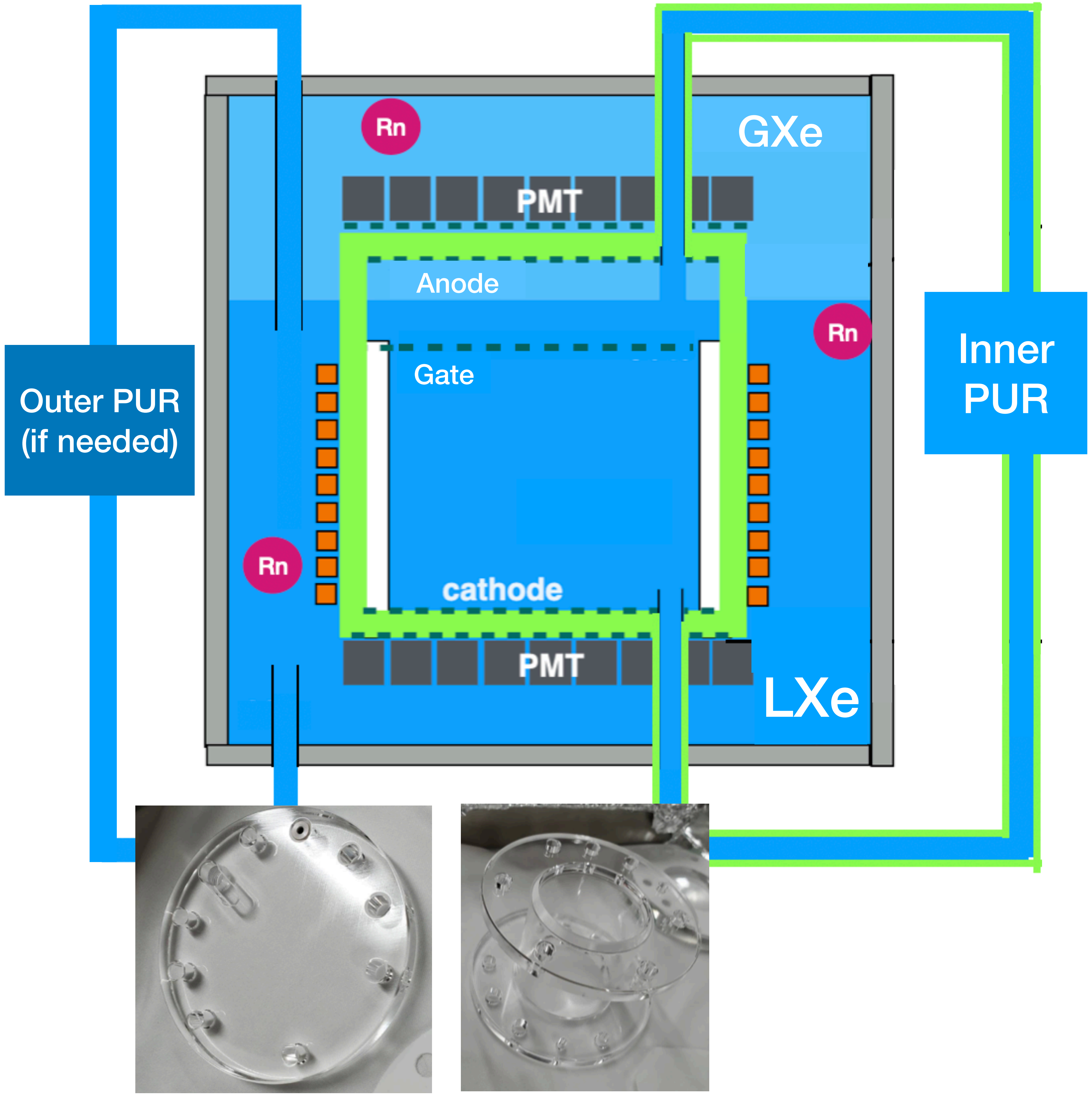


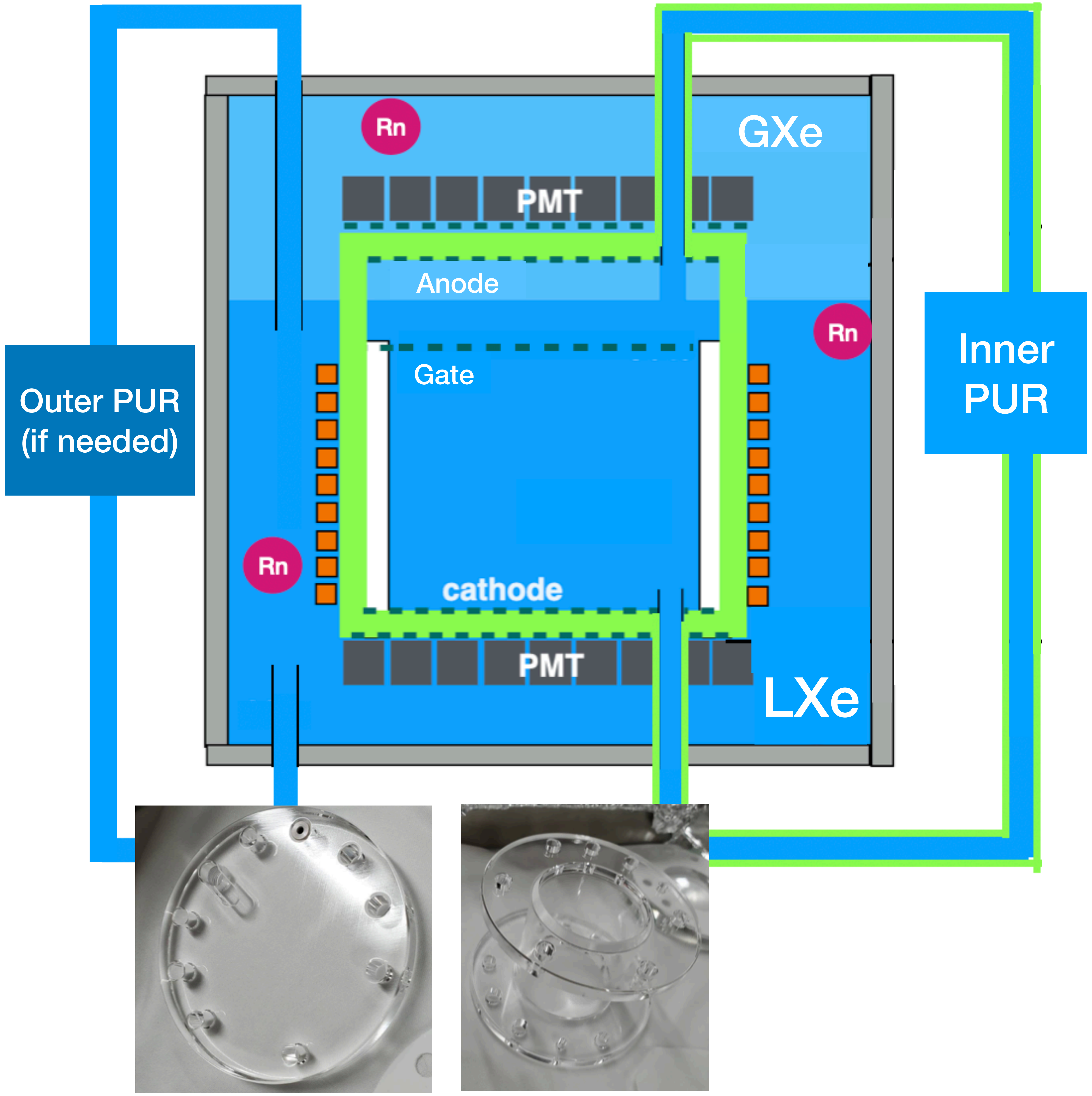
Advantages

- Almost no Rn222 emanation
- Less O_2/H_2O outgassing
- Coating electrode (no sagging)
  - Dedicated study ongoing

Challenges

- How tightly can we close?
- How to stabilize the detector?
- Which kind of materials for coating?

Hermetic Quartz TPC: Concepts



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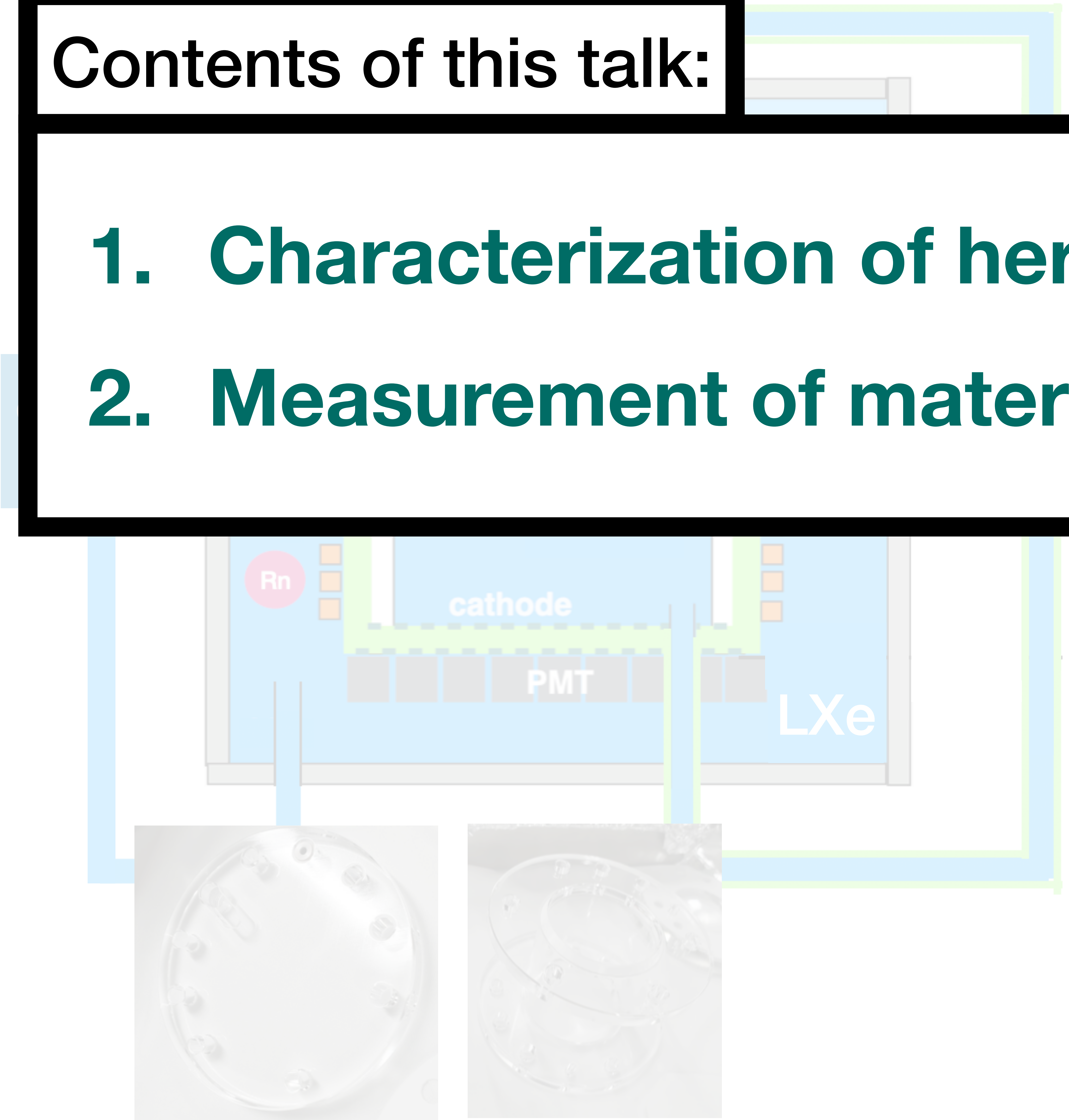
Content

Contents of this talk:

1. Characterization of hermetic chamber
2. Measurement of material QEs in LXe



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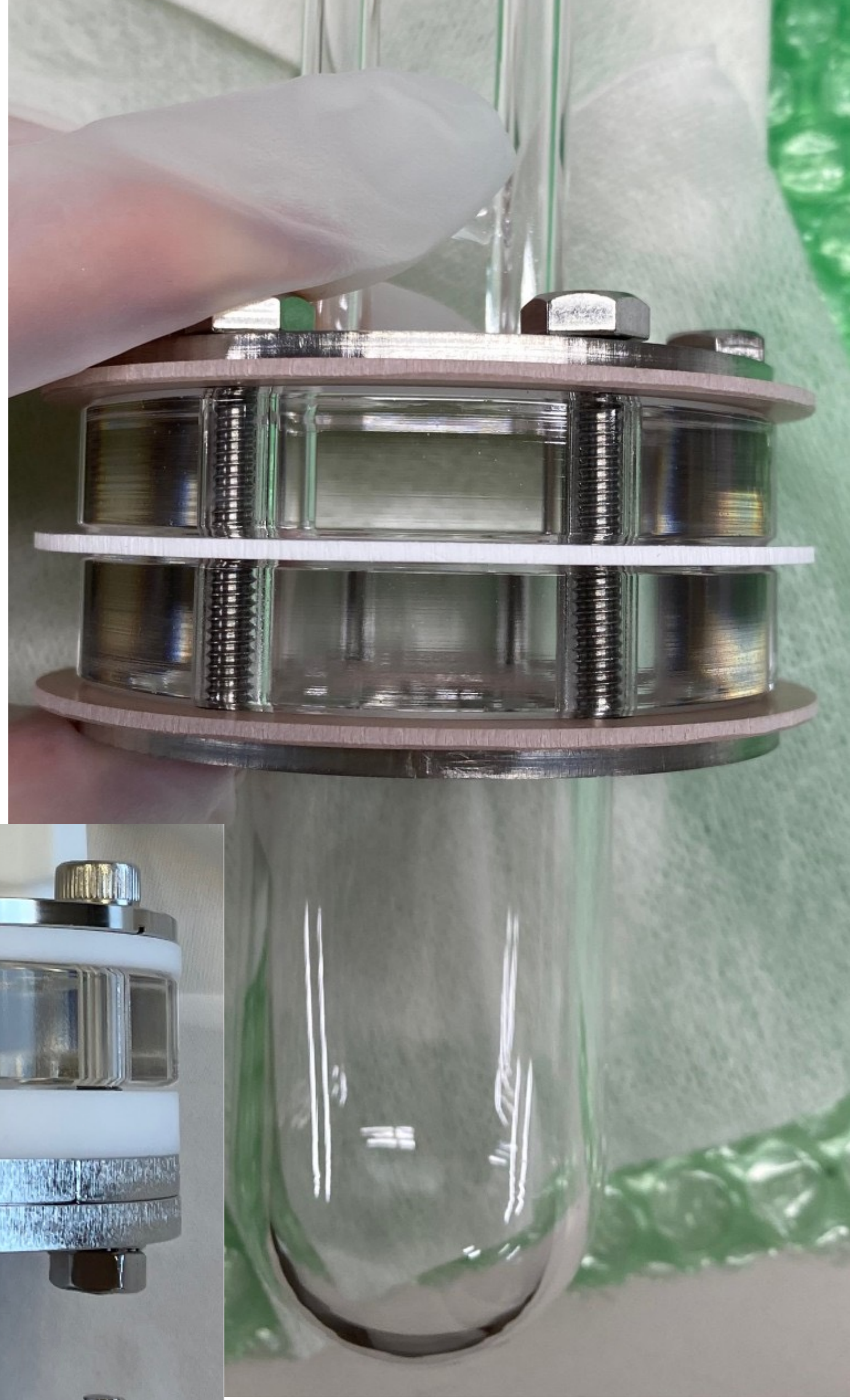
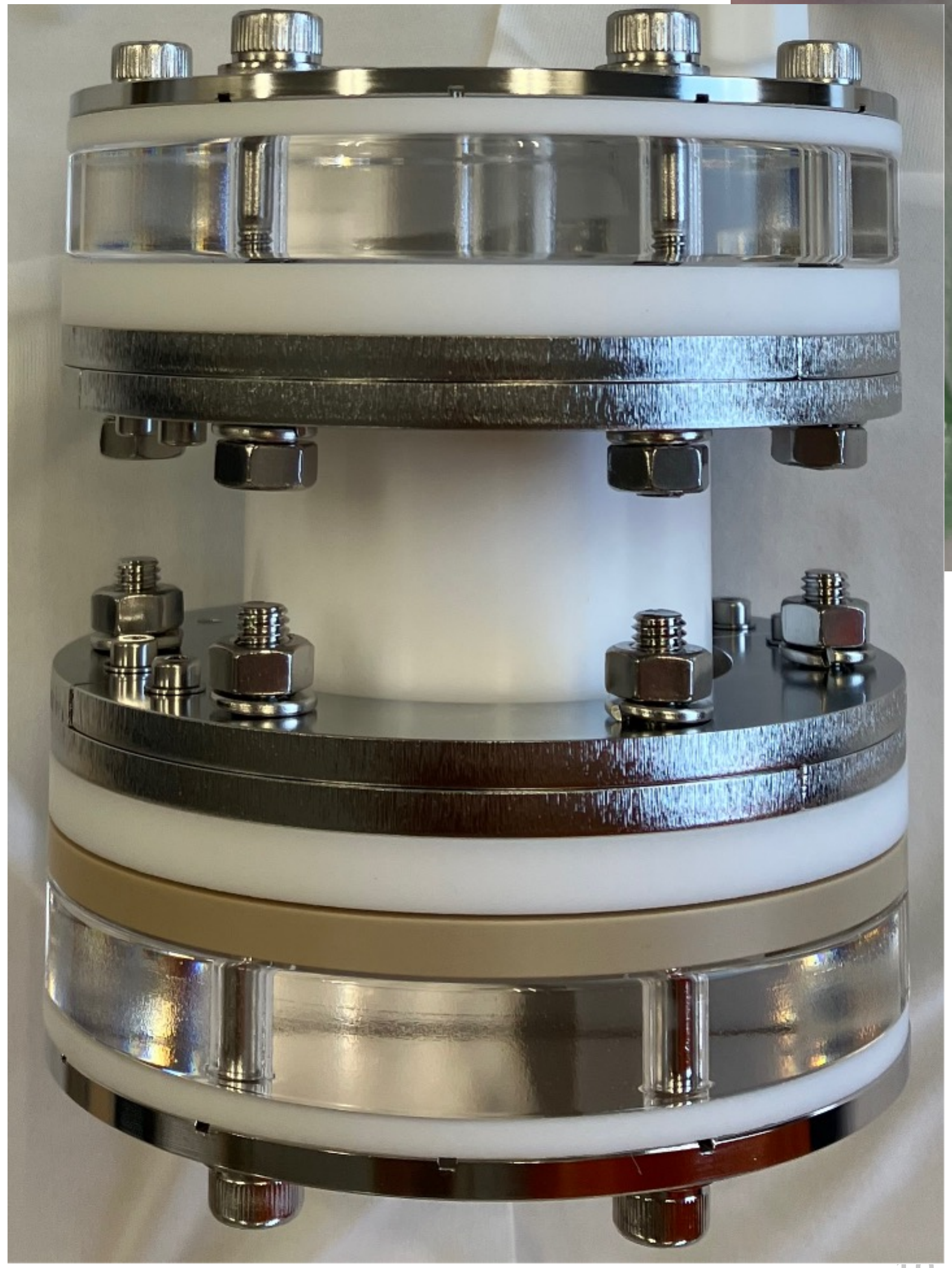
1: Characterization of hermetic chamber



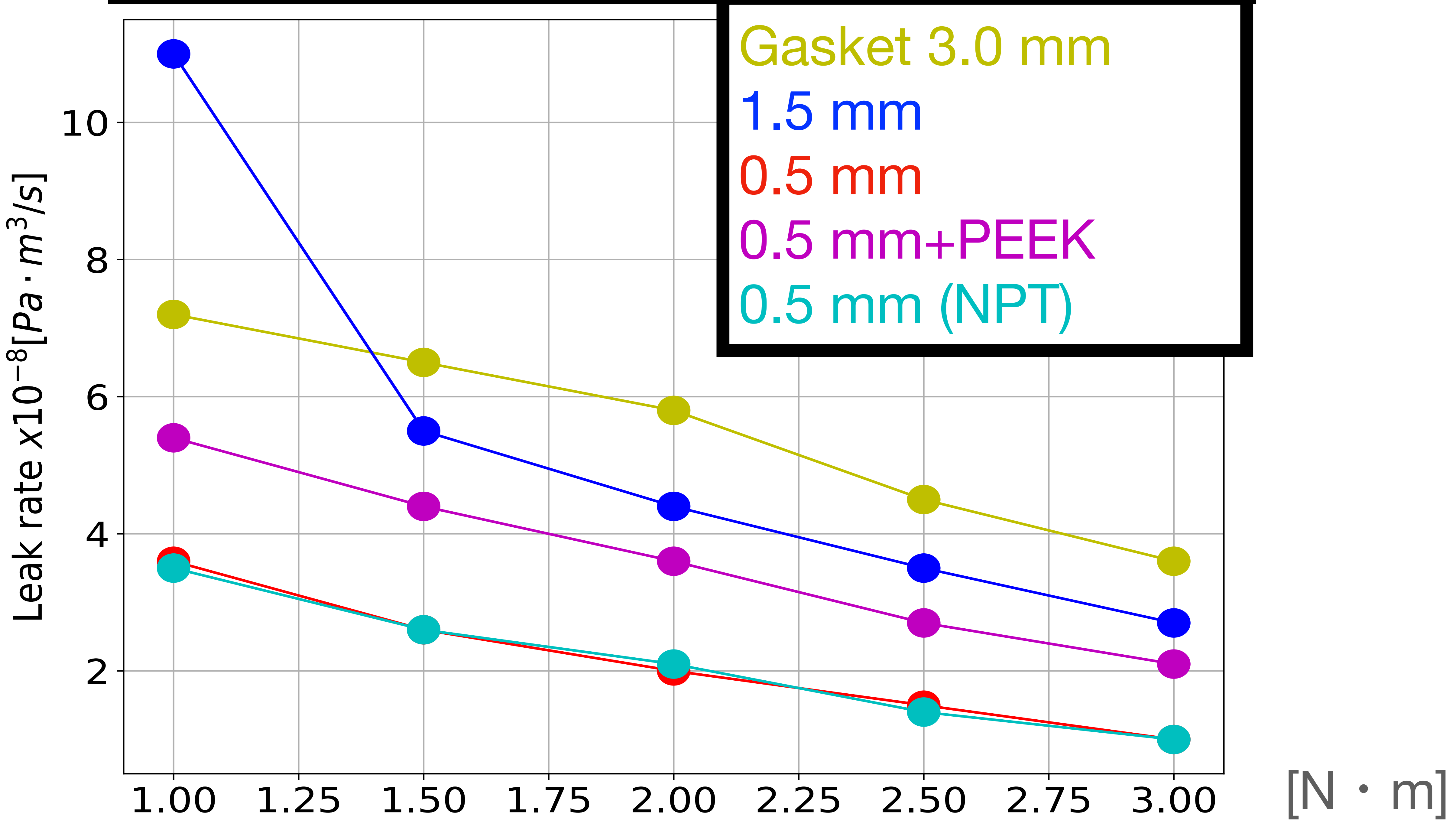


Test for Quartz flange conditions

Conditions of Quartz flange:

NPT screw or Branch-arm?
Gasket thickness?
With/Without spacer?
Torque?

Leak rate vs torque at each conditions



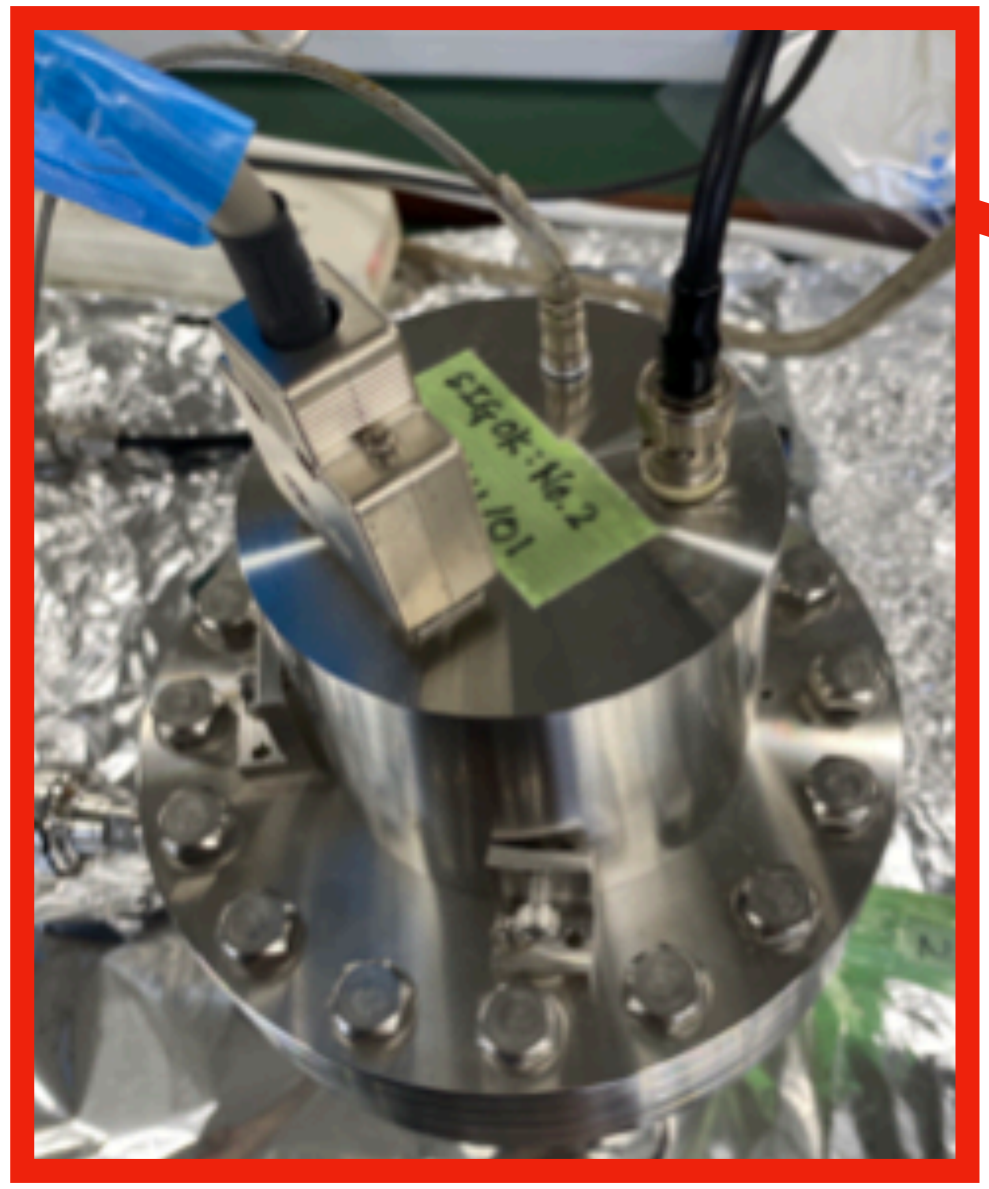
For TPC design:

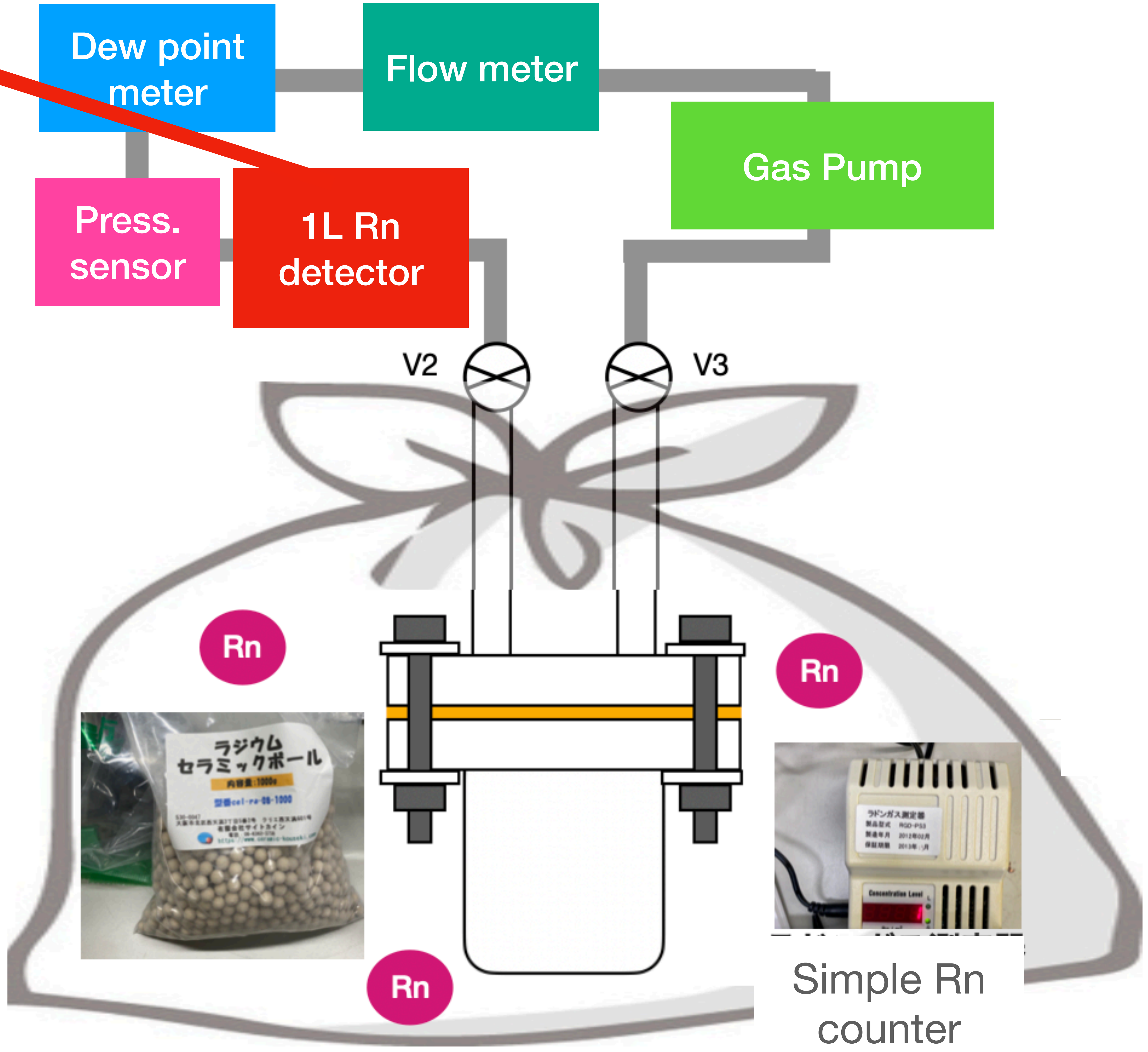
- Piping: NPT screw
- Gasket material: ePTFE
- Gasket thickness: 0.5 [mm]
- Use PEEK spacer

But: How about Rn shielding vs Leak rate?

Vacuum leak rate vs Rn shielding

- 1L Rn detector developed by SuperK group
  - PTEP Volume 2018, Issue 9, Sep 2018, 093H01





- Measurement done with GN2
- Inner Rn concentration was measured
  - BG run: without Rn source outside Quartz
  - Rn run: with Rn source outside Quartz

Vacuum leak rate vs Rn shielding

Rn reduction factor: $R_{in/out} = \dfrac{^{222}\text{Rn concentration inside quartz}}{^{222}\text{Rn concentration outside quartz}}$

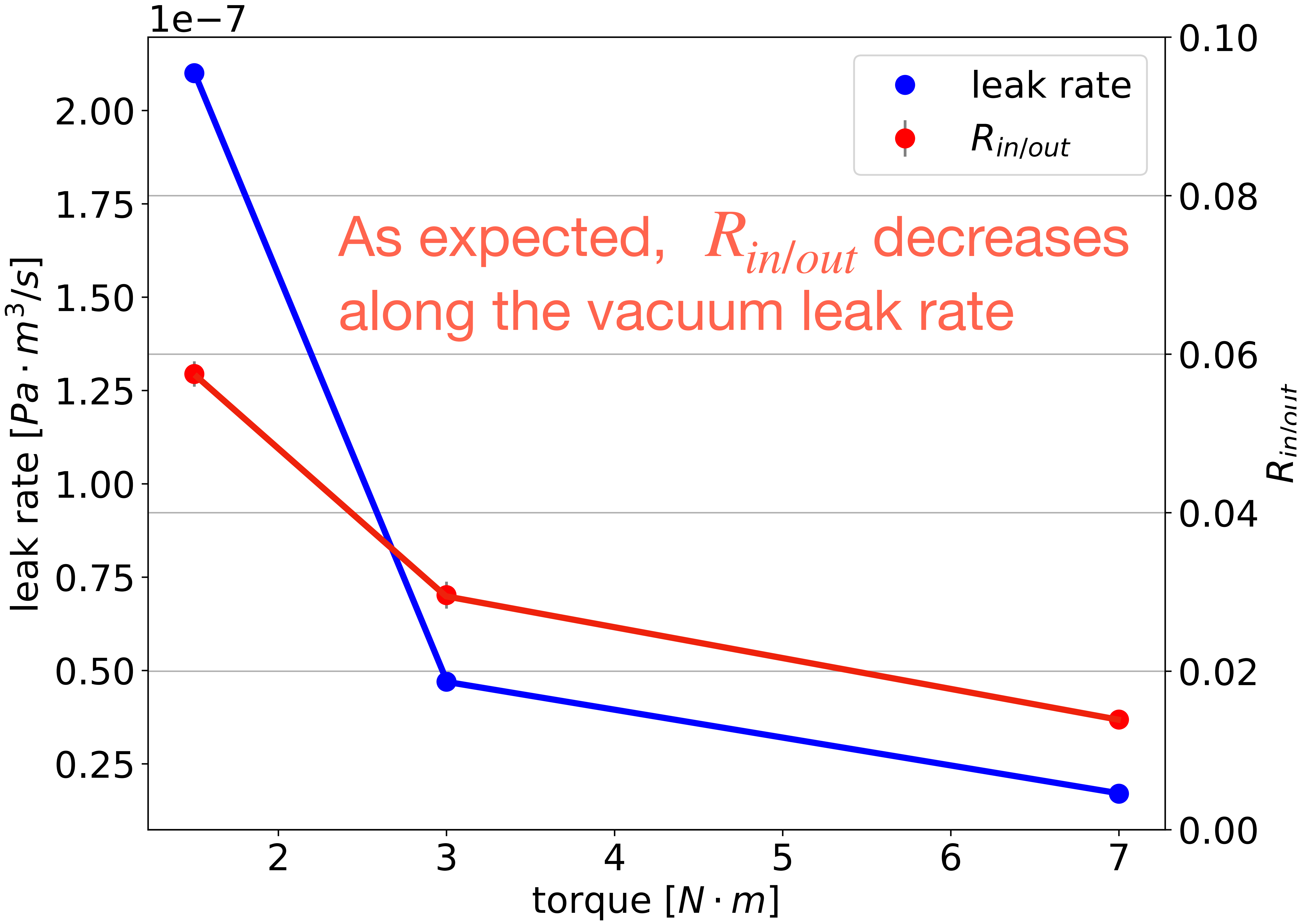
@Torque 7.0 [N · m]:

Leak rate:

1.7×10^{-8} [Pa · m^3/s]

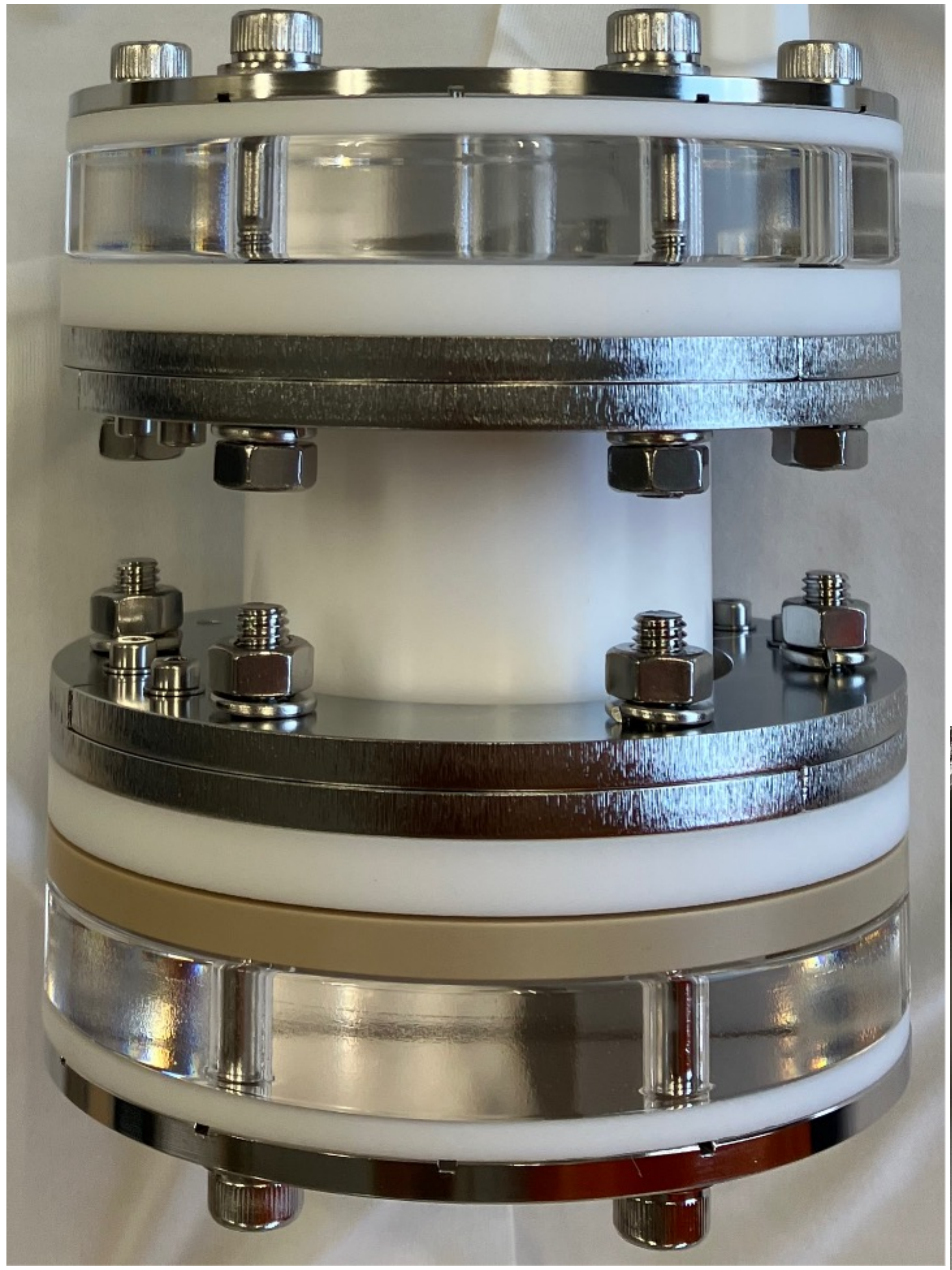
$R_{in/out}$:

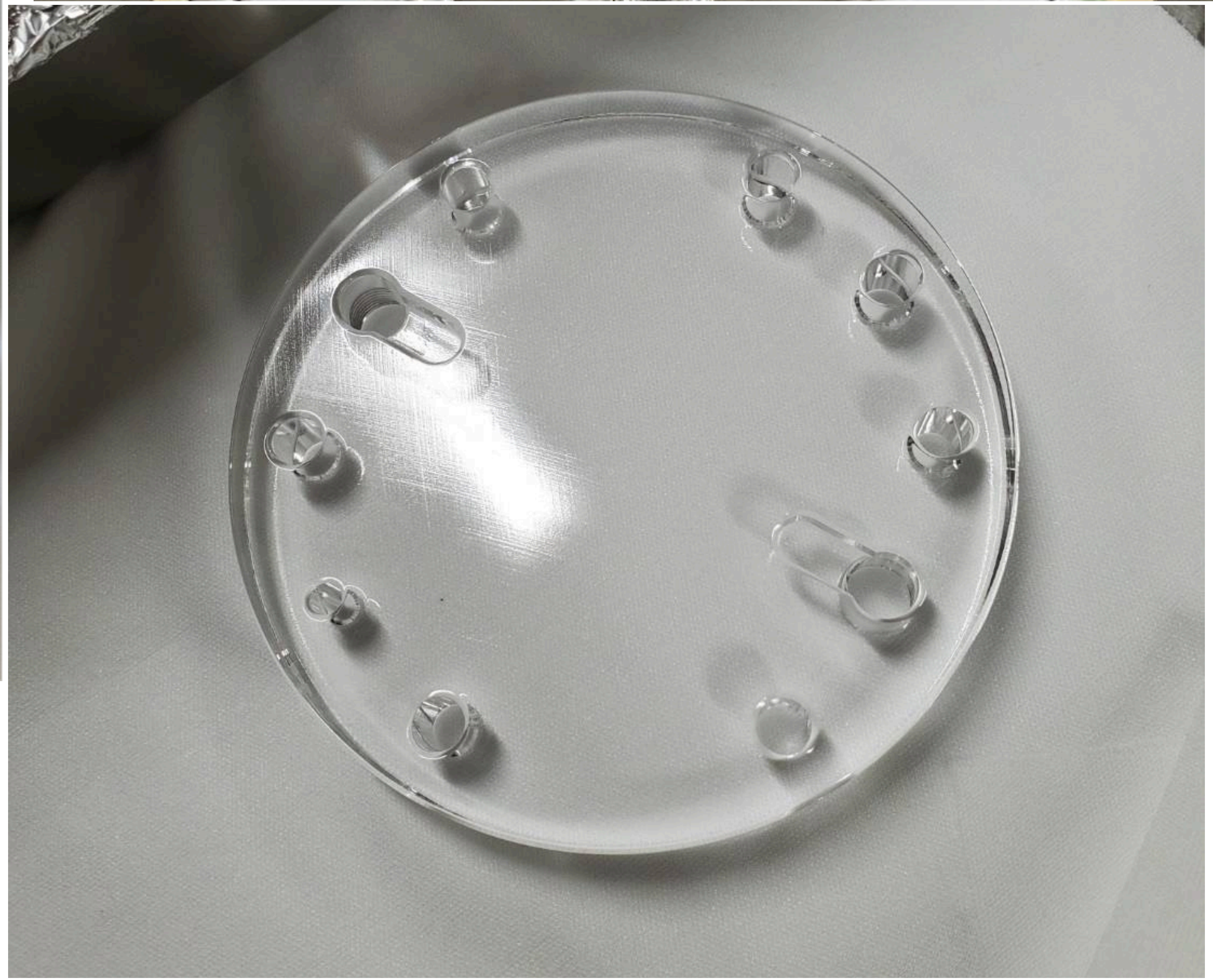
$(1.39 \pm 0.03) \times 10^{-2}$



Test with 0.1L detector

- Based on the result of the test, we designed the 0.1L R&D detector
  - Top/Bottom flange: quartz
  - Body: Quartz or PTFE
  - Different gasket shape
- The assembly and vacuum test showed difficulty in quartz body to apply enough torque
  - PTFE body + thin gasket is chosen
- More details in Ryuta Miyata's poster





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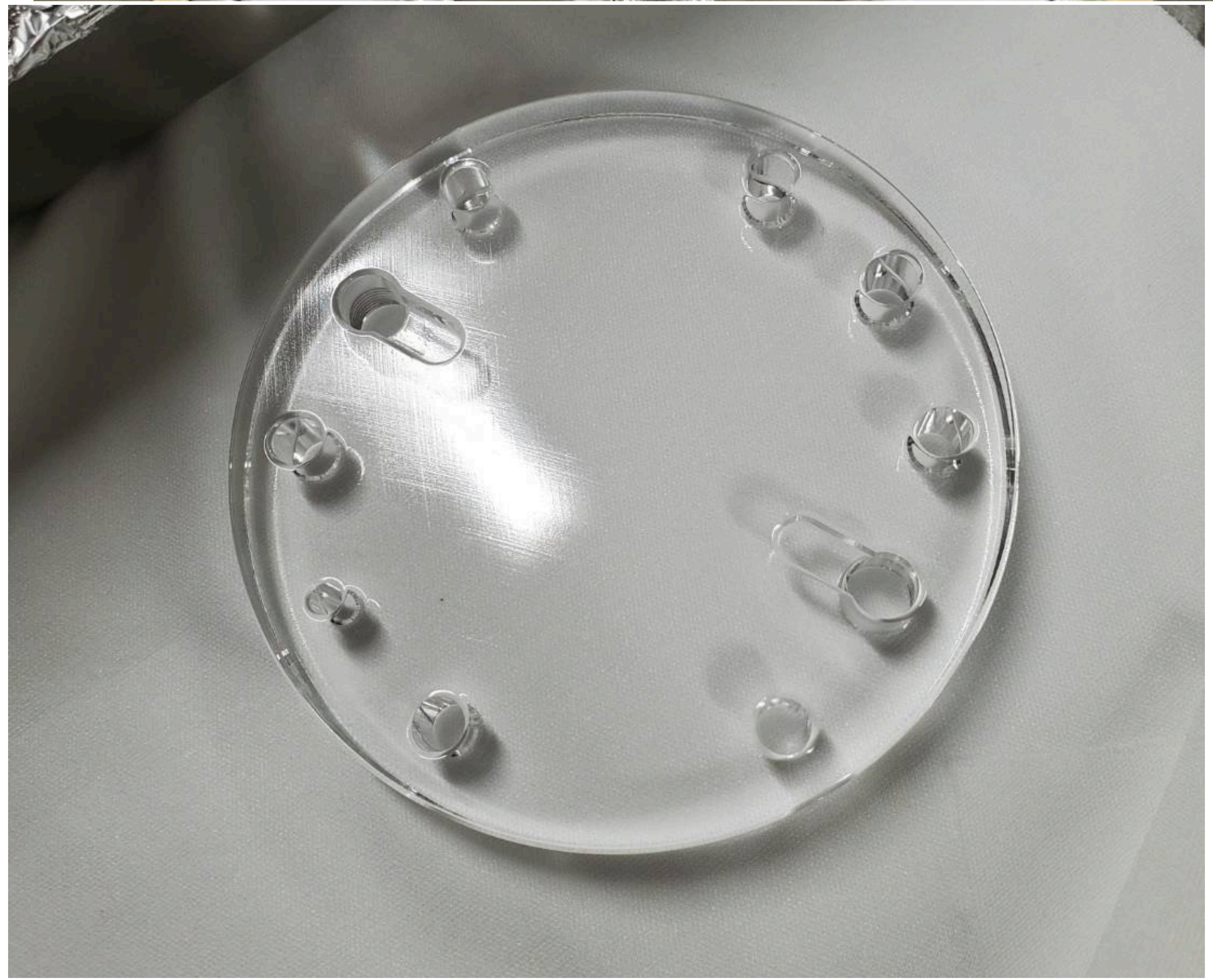

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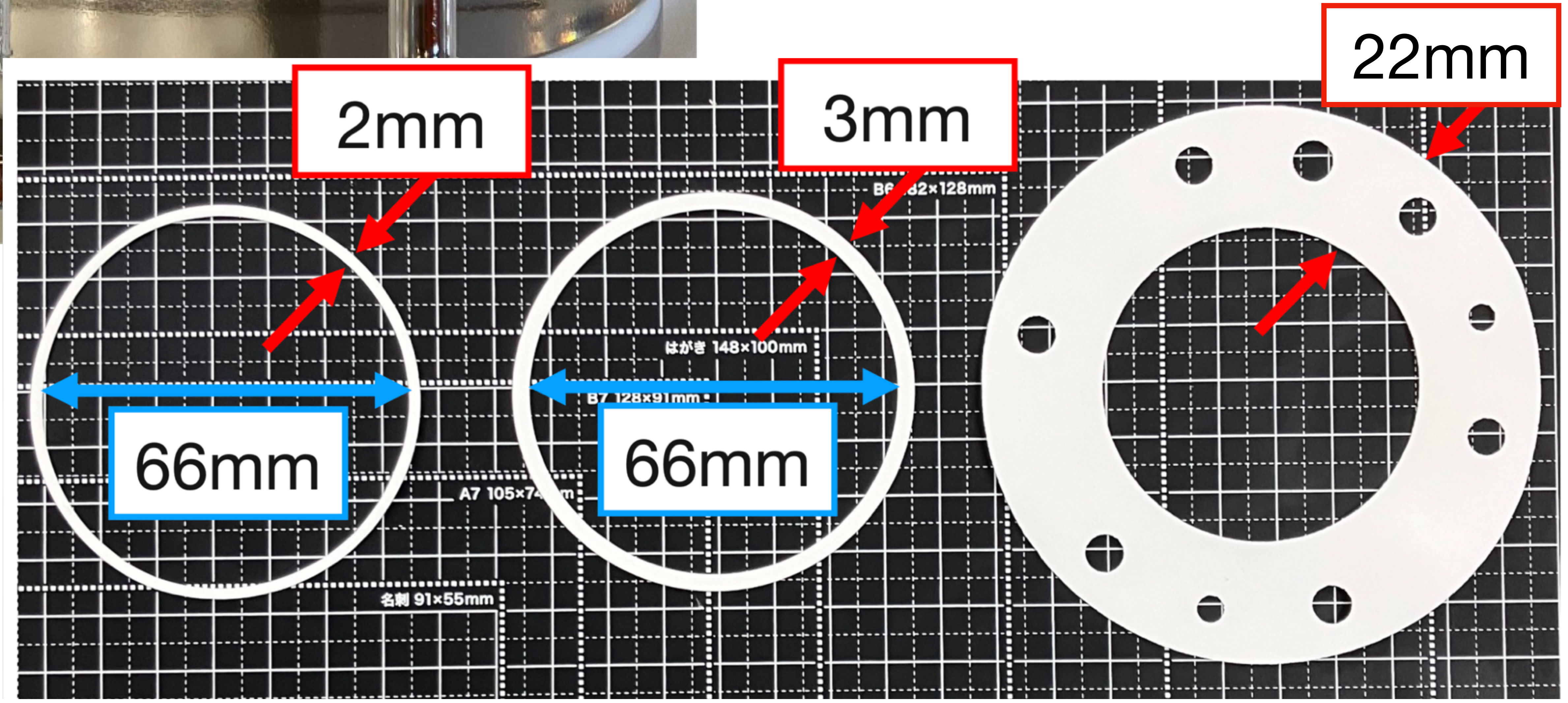

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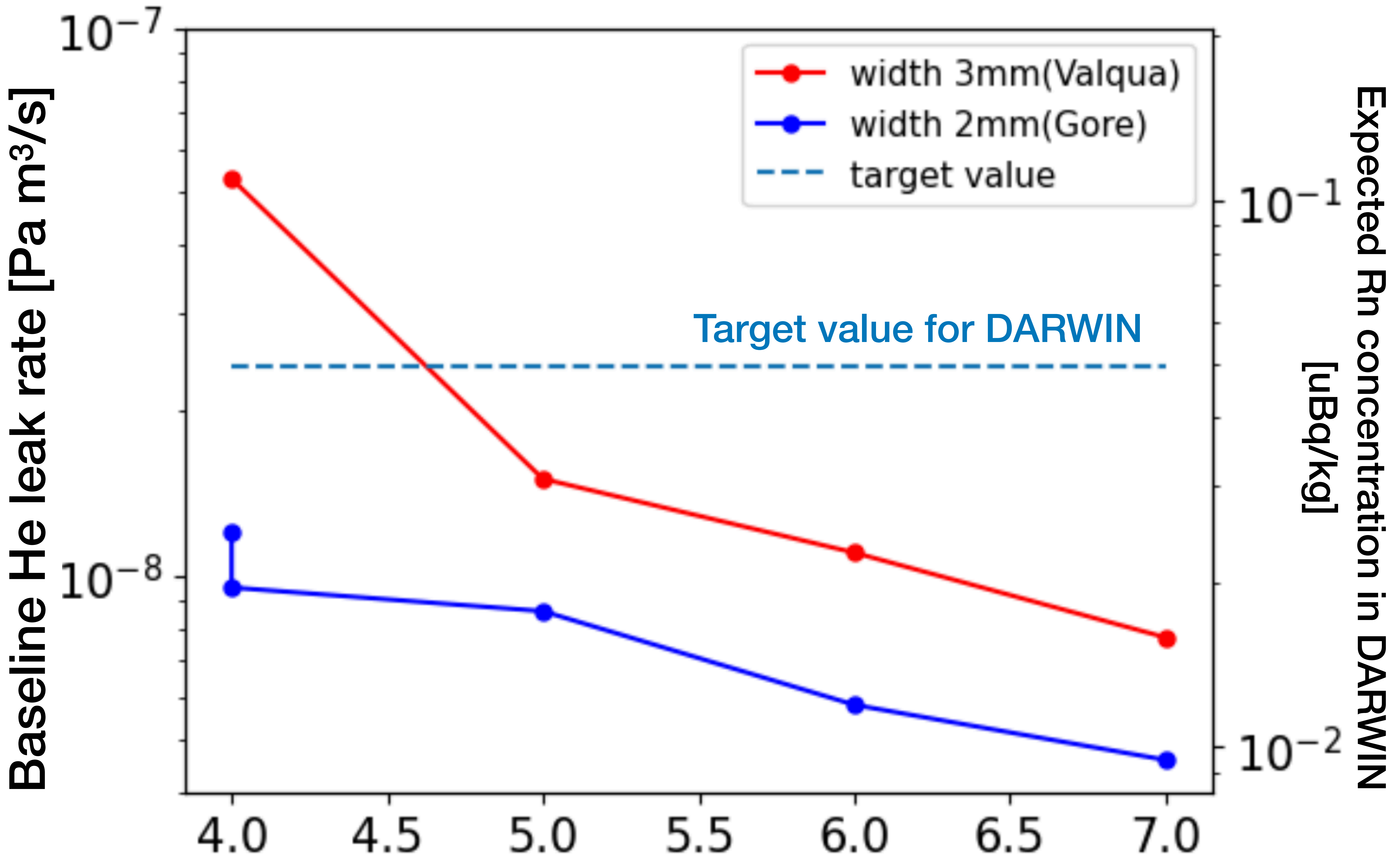
- The result of vacuum test with PTFE body + thin gasket
  - Same vacuum level with previous test
  - Other conditions (ex. quartz body) has ~x10 larger leak rate
  - Blue: estimated Rn leak rate in DARWIN based on the He leak rate
- Also long term (1month) test showed no significant increase of leak rate
- Currently GN2 test is ongoing
- LXe system is also in preparation, plan to test by this summer



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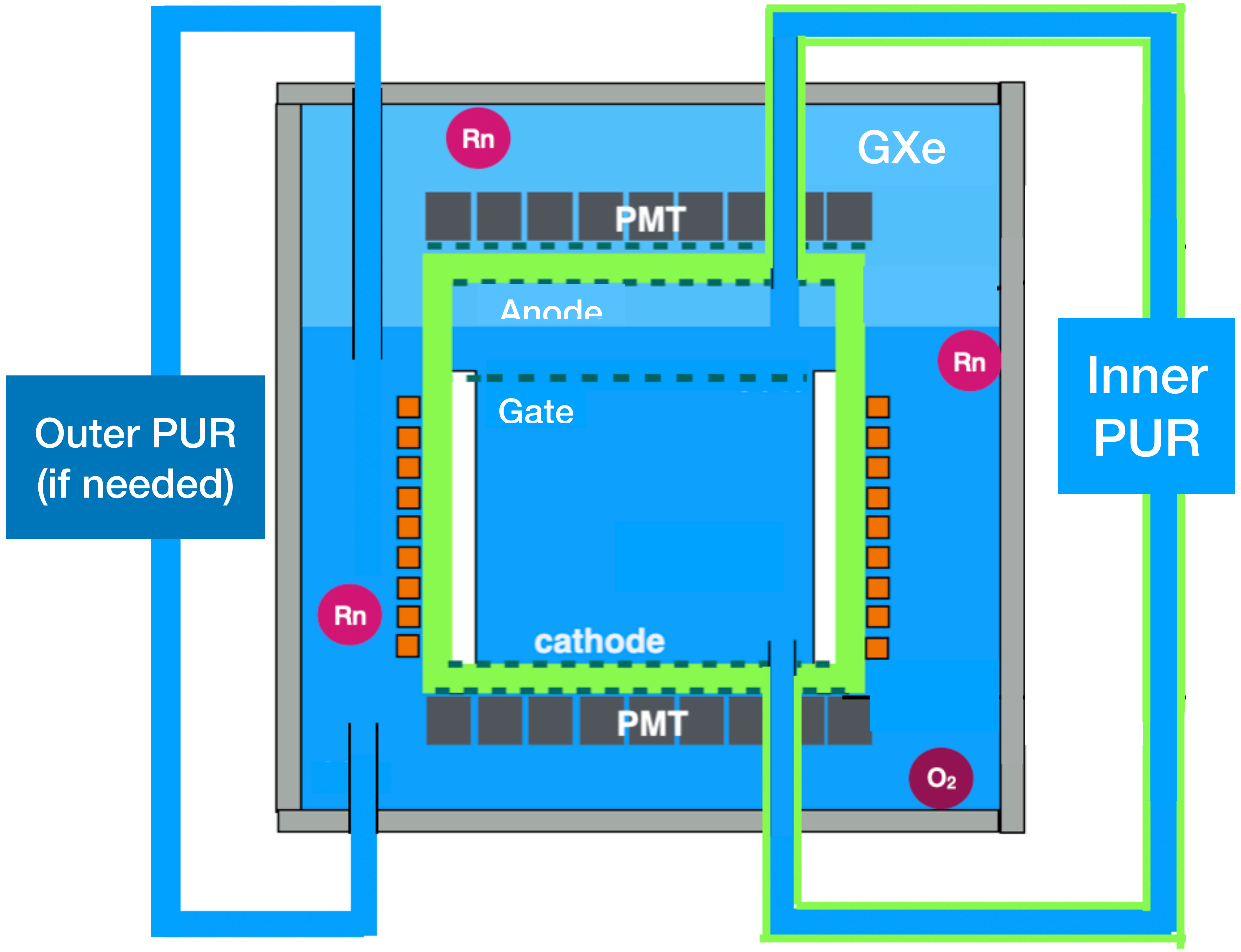
2: Measurement of material QEs in LXe

Coating materials

- Advantage of hermetic chamber: static quartz structure
  - Anode/Cathode can be coated on top of the plate
  - Mechanically stable (ex. no sagging)

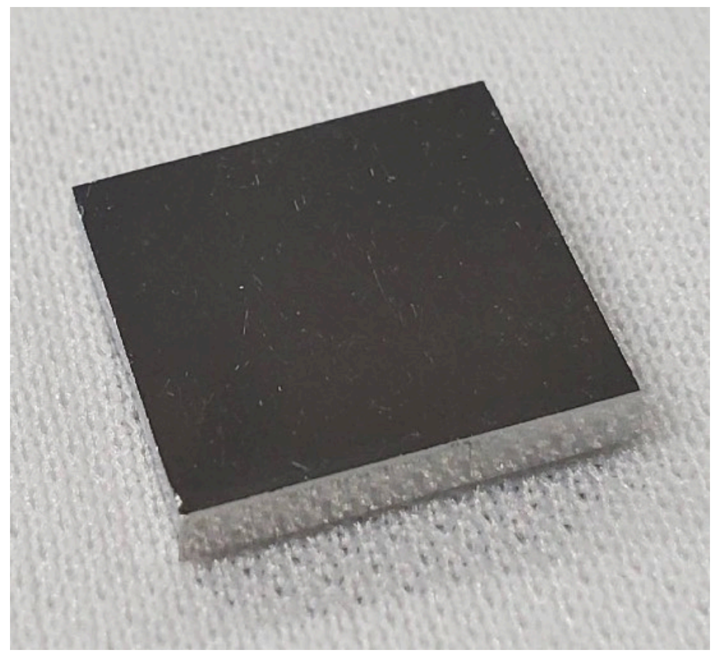
- One of the requirement for the coating material: low quantum efficiency (QE)
  - To suppress the single-E background from photoelectric effect

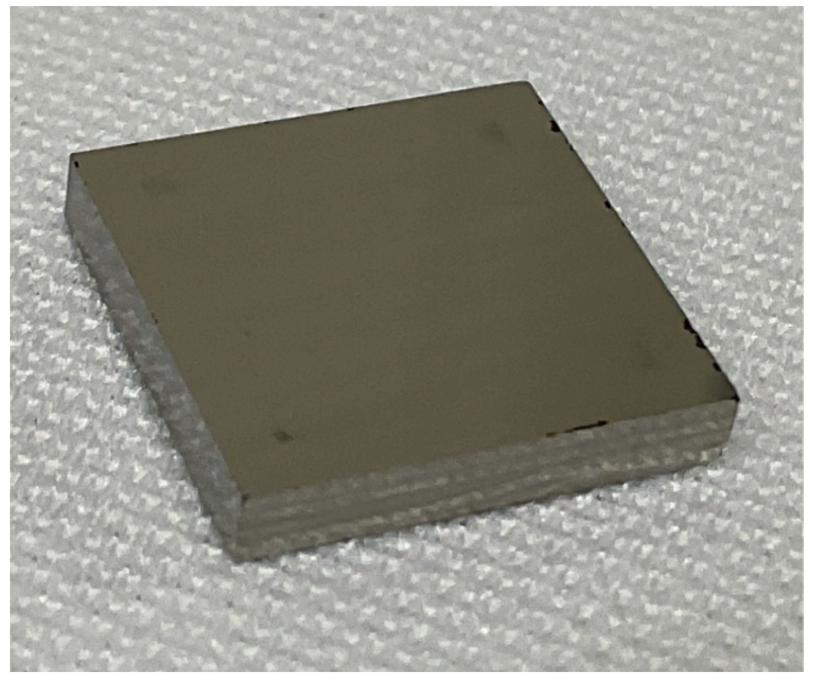
=> Measure the quantum efficiencies of materials in LXe!

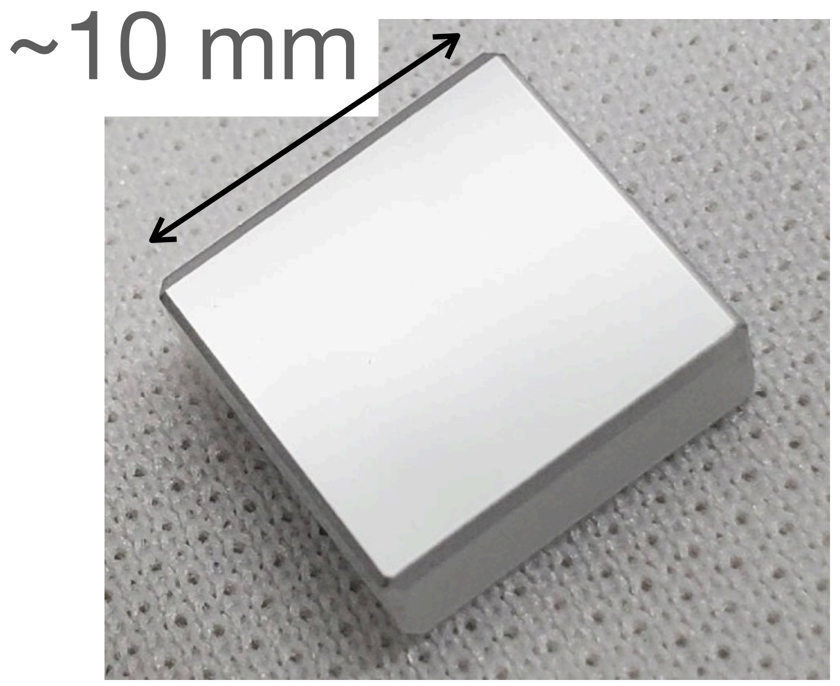


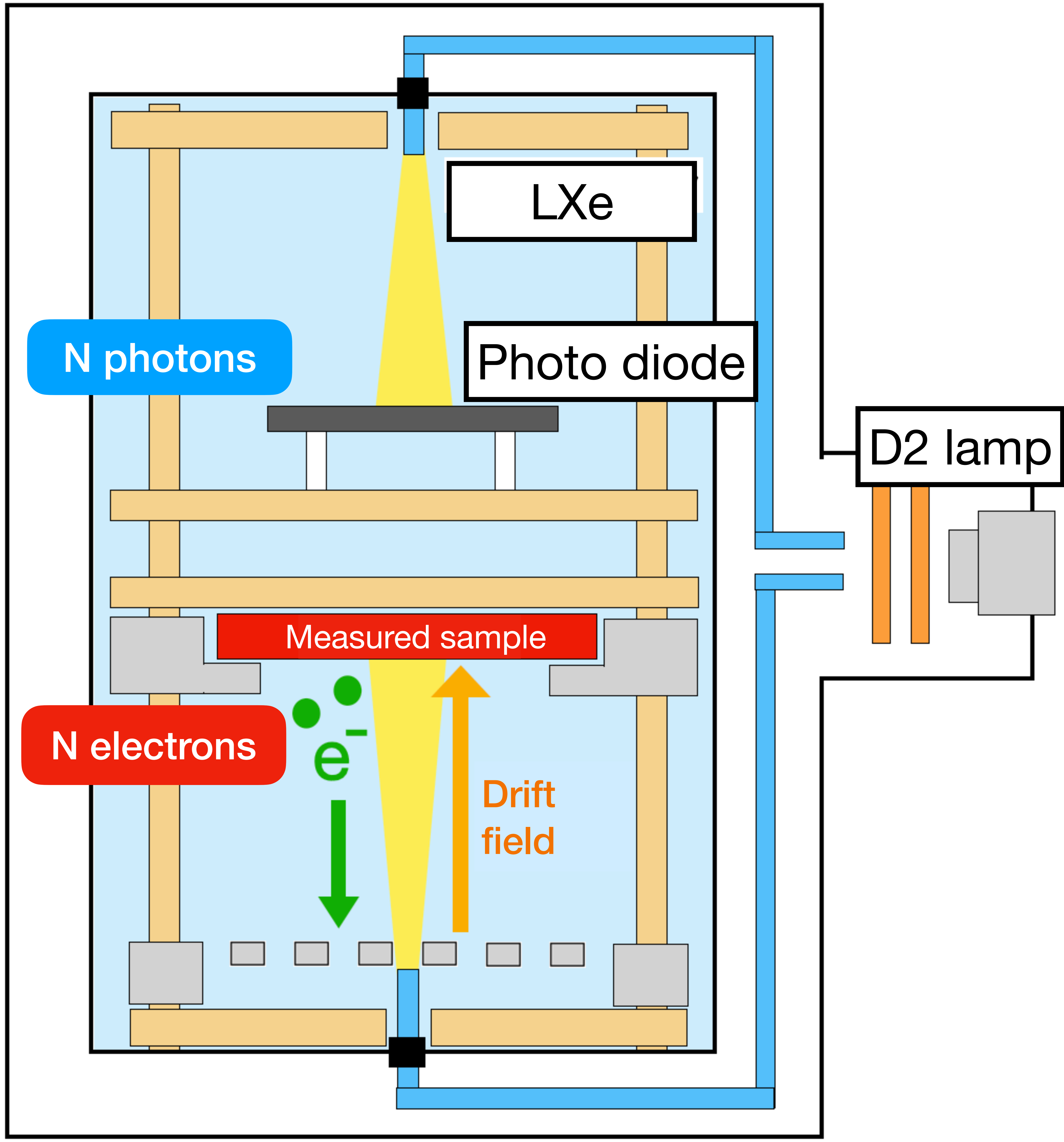
Measurement setup

- Injecting the VUV light from D2 lamp using band -pass filter and optical fiber
  - λ= 179.5 ± 7.4 nm
- Measure photons with PD, electrons by included current
- Three materials are tested:
  - Stainless steel: being used in G2 detectors
  - Pt: High work function metal (> SS)
  - Al + MgF_2: coated by insulator on top of metal









Measurement setup

QE = (N of Electrons)/(N of Photons)

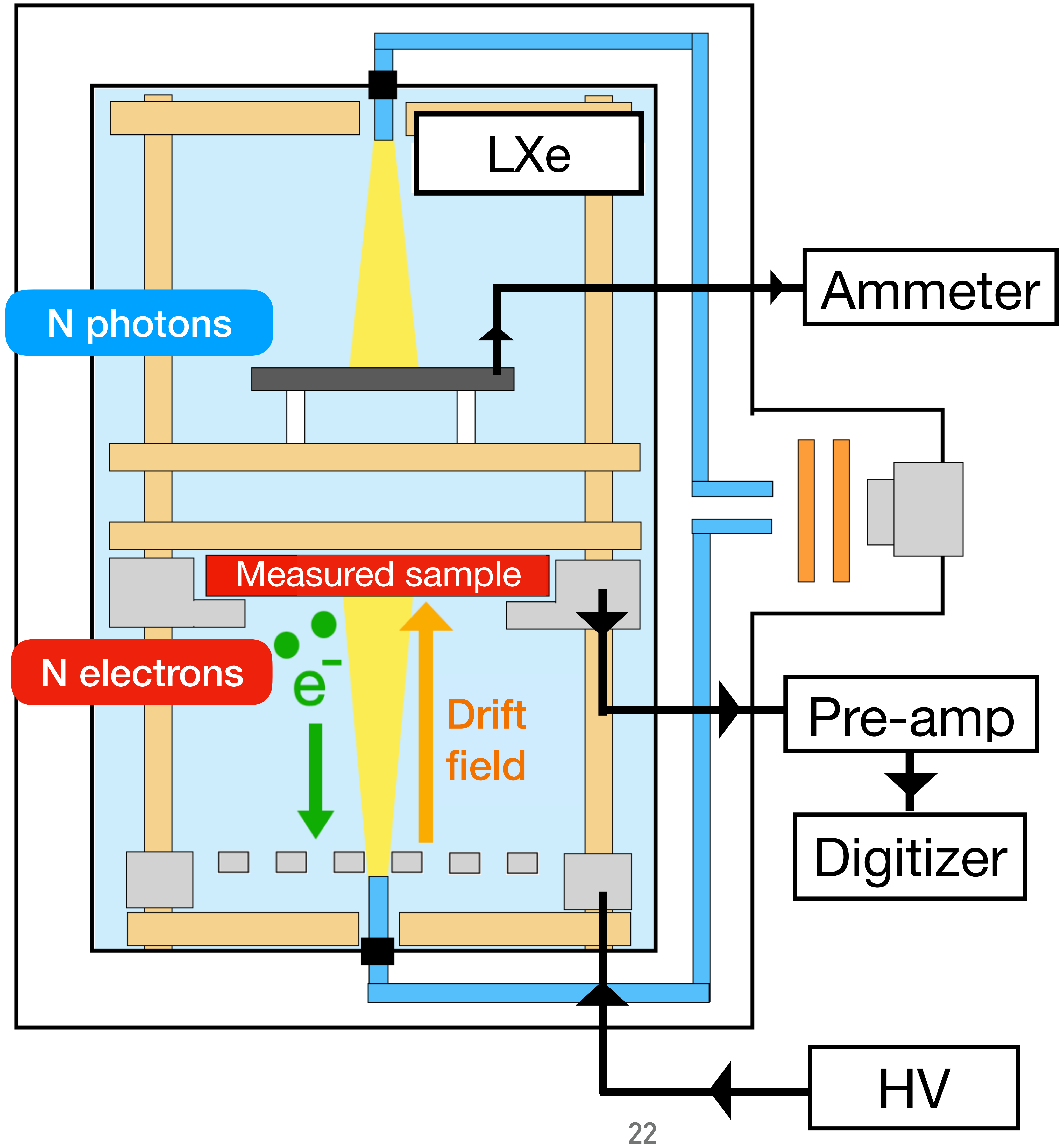
Photons

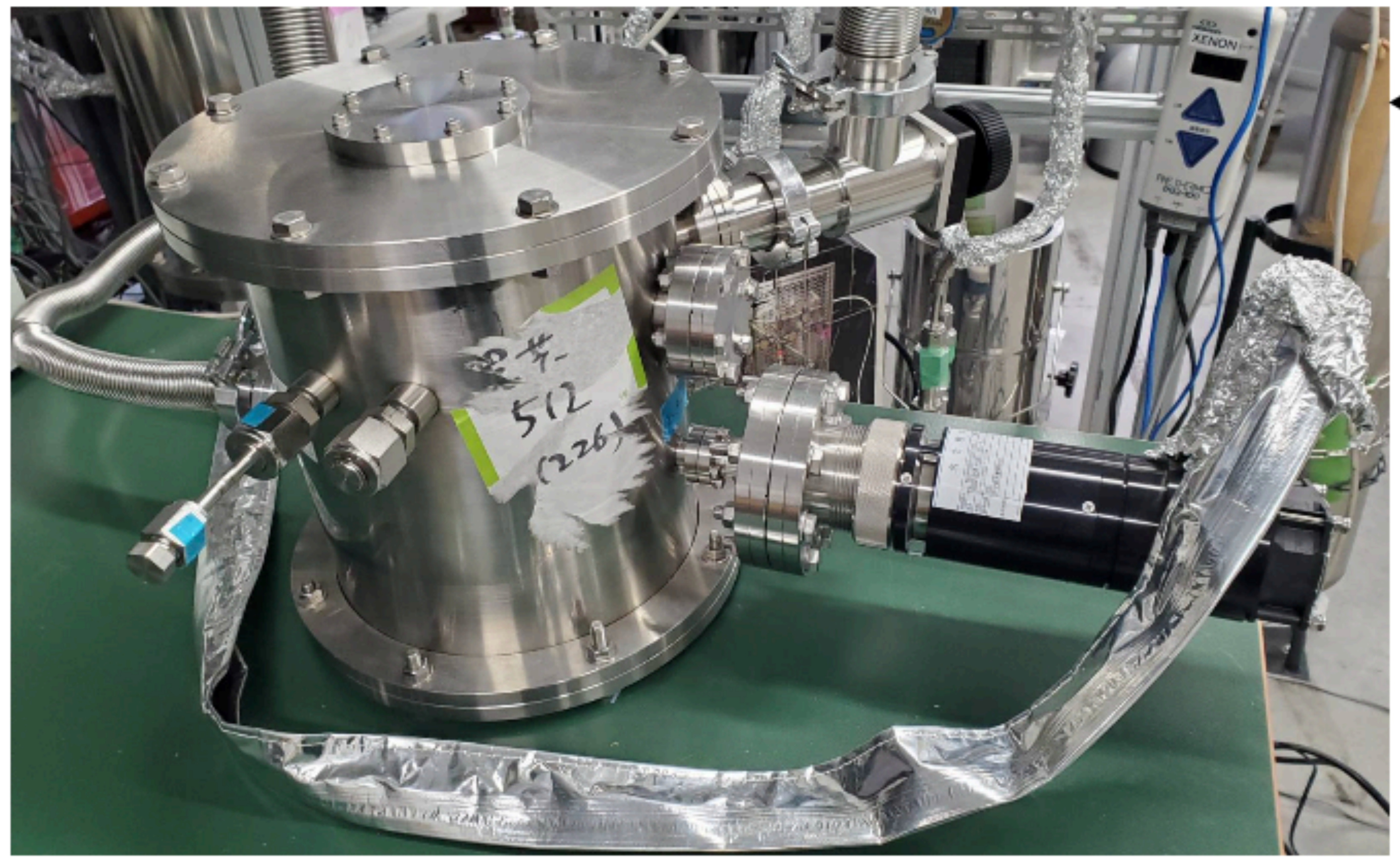
1. Measure the signal from PD using ammeter

Electrons

1. Electrons are emitted via photoelectric effect
2. Drift them with the e-field between anode/cathode
3. Measure the induced current using charge-sensitive pre-amplifier

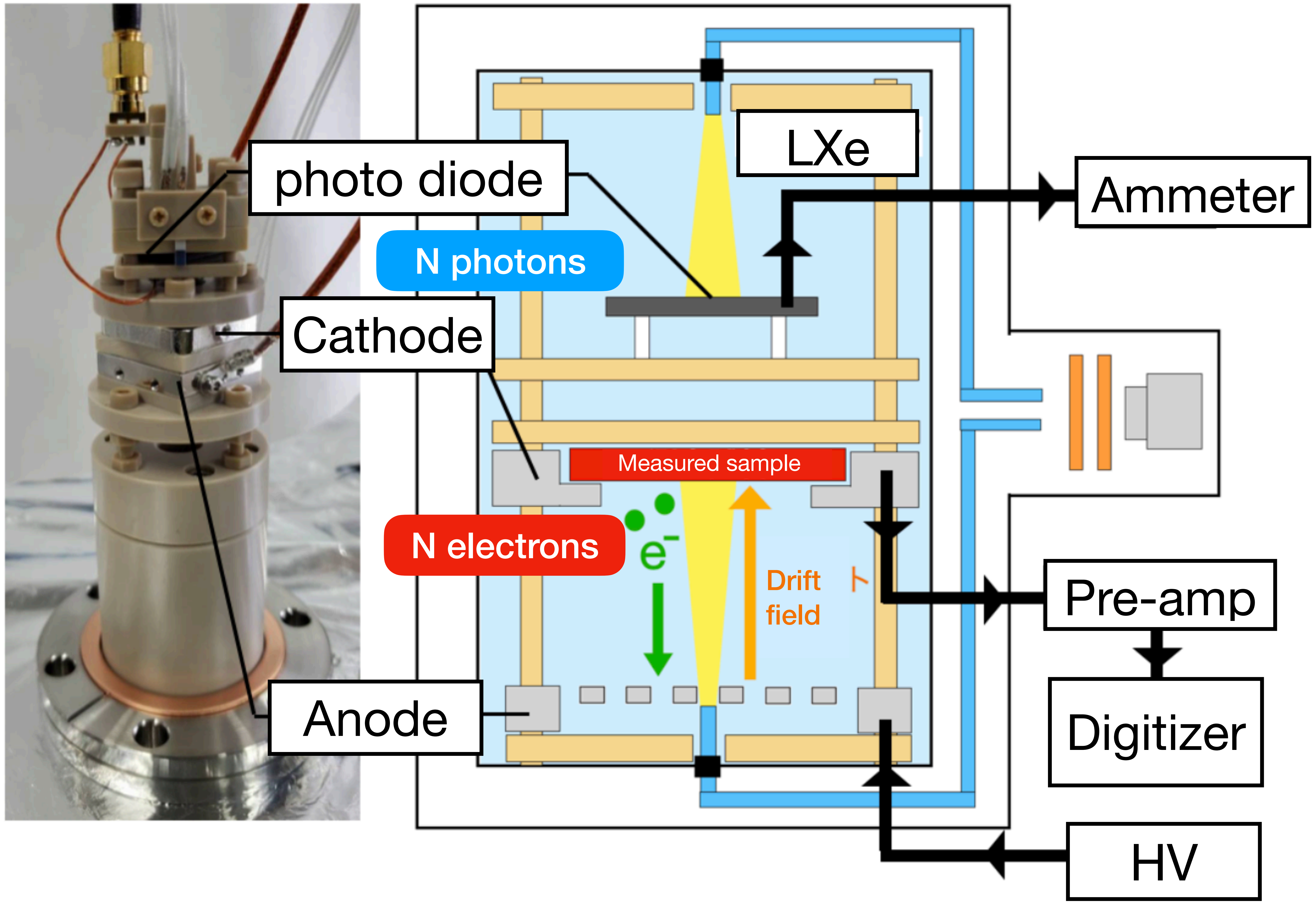
- The measurement has been performed with lamp ON/OFF and different drift fields





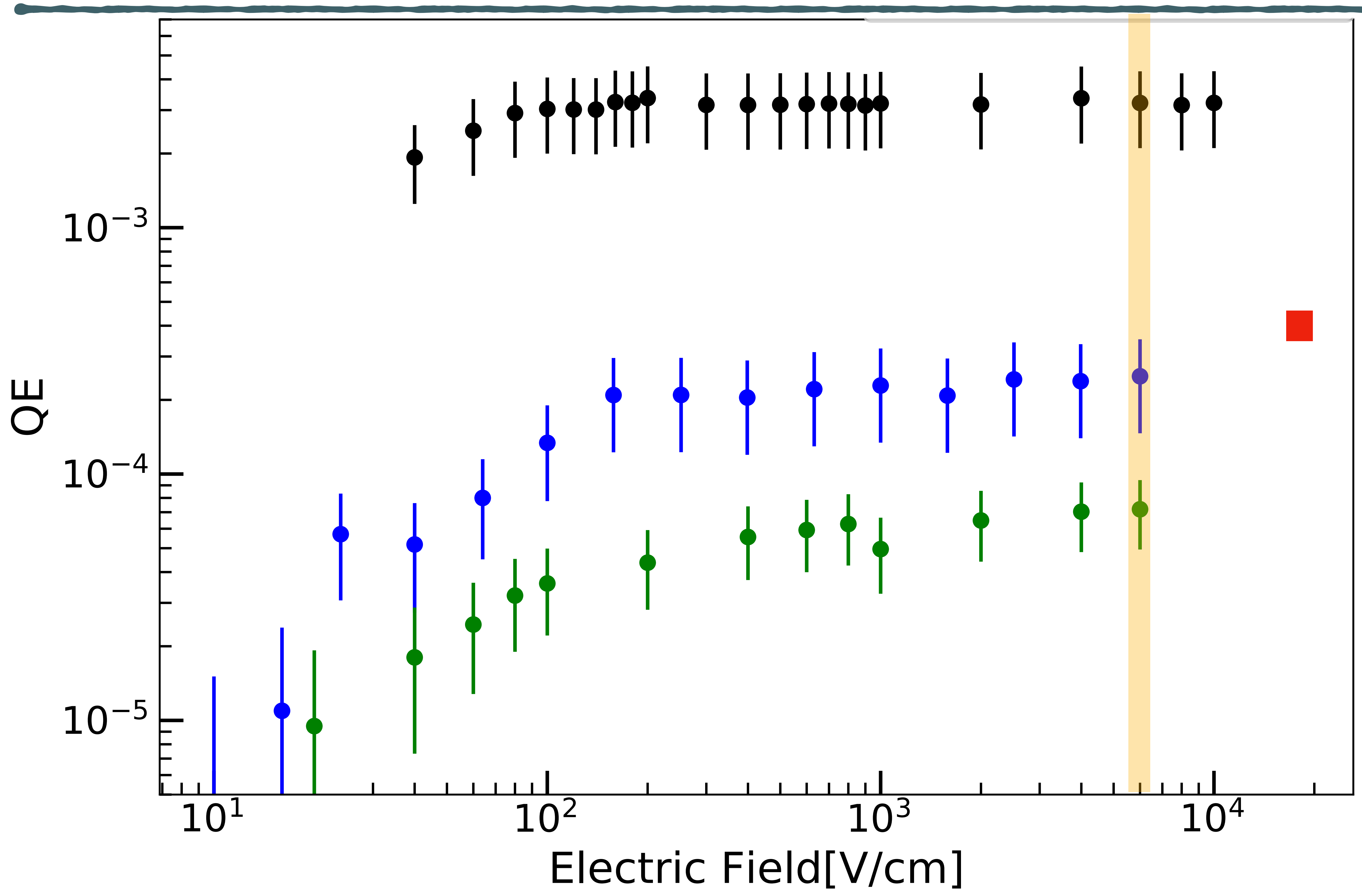
Light source
- D2 lamp + band-pass filter
- Located in the vacuum chamber

Detector setup



Detector chamber mounted in LXe setup

Result of the measurement in LXe



	QE @ 6 kV/cm
: Pt	$(3.21 \pm 1.10) \times 10^{-3}$
: SS	$(2.49 \pm 1.03) \times 10^{-4}$
: Al+MgF_2	$(7.19 \pm 2.25) \times 10^{-5}$

■ : QE of SS at 18kV, from LUX $\sim 4.0 \times 10^{-4}$

(LUX collaboration, PhysRevD.104.012011)

- **QE(Pt)** > **QE(SS)**
  - Work function of Pt is higher than Stainless Steel, but QE is also higher
  - Passive layer on top of Stainless Steel effectively increase the work function?
- **QE(Al + MgF_2)** / **QE(SS)** = 0.29 ± 0.15
  - We can expect to suppress the photo-ionization by using **MgF_2**

Summary

- **Hermetic quartz TPC:**
  - Further Rn reduction for future liquid xenon detectors
  - Quartz plates can be coated and used as electrodes
- **Test of the quartz flange was performed and achieved:**
  - Suppressing the Rn concentration to ~1.4% with small test flange
  - Currently the test with 0.1L detector is ongoing
    - LXe system being prepared
- **The measurement of QE for coating materials was also performed:**
  - QE for Pt, Stainless steel and Al+MgF_2 are measured
  - Al+MgF_2 showed the lowest QE: ~30% of SS
  - The single phase S2 production with microstrip coated electrode is also ongoing

BACK UP